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Standard Practices and Guidance for the Selection and Use of Time-Based Information on NextGen ATC Displays

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Technical Report

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16. Abstract

Objective: The purpose of this Next Generation Air Transportation (NextGen) research is to evaluate time-based information display (TBID) concepts and examine standard practices for the display and use of time-based information on Terminal Air Traffic Control (ATC) displays. Background: We reviewed literature to identify elements of TBIDs that were useful in prior research. This review showed the importance of color coding, timelines, slot markers, and advisories for TBIDs. **Method**: We conducted two usability studies to further examine TBIDs in the Terminal Radar Approach Control (TRACON). The first analysis used two subject matter experts (SMEs) to examine the timeline graphical user interface (T-GUI), planview graphical user interface (P-GUI), color coding, timelines, slot markers, and the exact presentation of time (i.e., minutes and fractions of minutes with early/late [E/L] indicators) with a non-interactive prototype. The second analysis used a dynamic low-fidelity prototype to further examine a TBID with color coding, slot markers, and the exact presentation of time with a P-GUI. **Results**: The data were entirely subjective and no task performance data were obtained or used to evaluate the TBID alternatives. Findings from the first usability study showed that a T-GUI was poorly suited for TRACON operations, and that further development should focus on color coding, slot markers, and the exact presentation of time with a P-GUI. The second usability study showed a preference to use color coding and slot markers for TBID. Participants also expressed a preference to include speed advisories, however, only four participants' data were used in the scenario-based evaluation, and statistical power was not computed or reported in the results. **Conclusion**: Previously published research that demonstrated an advantage of timeline displays primarily used tasks that required operators to manage en route traffic or traffic flow in a more strategic way. NextGen TBIDs for TRACON operations should include color coding and slot markers to present time-based information. Displays should replace redundant information (e.g., exact presentation of time) with advisories that provide information about how to resolve problems with scheduling. **Applications**: This research supports future development of a NextGen TBID in the TRACON. The study obtained limited, subjective data that we evaluated to support what we are providing as our initial recommendations for NextGen TBIDs.

17. Key Words Time-based information display Air Traffic Control TRACON Graphical User Interface	**18. Distribution Statement** This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov

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Executive Summary

As the Next Generation Air Transportation System (NextGen) increases implementation of time-based flow management, there is a growing need to understand the human factors and usability issues associated with displaying time-based information. The Human Factors Branch (ANG-E25) at the FAA William J. Hughes Technical Center conducted this research to examine NextGen time-based information display (TBID) concepts for the Human Factors Division (ANG-C1). The purpose of this research is to evaluate TBID concepts and examine standard practices for the display and use of time-based information on Terminal Radar Approach Control (TRACON) radar displays. The specific objectives of this research are:

- to research prior efforts to present time-based information in domains relevant to air traffic control (ATC),
- to develop and evaluate prototype methods for presenting time-based information in ATC, and
- to provide guidance and standard practices for presenting time-based information on NextGen ATC displays.

We completed these objectives in three stages. First, we conducted a literature review for an annotated bibliography (Fincannon, Racine, & Truitt, 2016). We summarize the most relevant findings of the literature review in Section 2 of this report. Second, we narrowed the scope of the research to focus on applications in TRACON operations, and we worked with two subject matter experts (SMEs) to develop five prototypes for an initial usability analysis. Third, after using the initial usability analysis to select an optimal design, we developed a dynamic, low-fidelity prototype for a second usability analysis and further assessment of TBID concepts. We used feedback from the two usability analyses and the annotated bibliography to provide recommendations to guide the design of TBIDs that we present in this technical report.

From the literature review, we identified four major elements of time-based information design that were successful in prior research. The literature supported the use of color coding to direct a controller's attention to a display and highlight important information. Timelines provided information about estimated time of arrival (ETA) and scheduled time of arrival (STA) in a timeline graphical user interface (T-GUI), which helped organize aircraft in en route air traffic management (ATM). Slot markers provided a spatial representation of aircraft locations in a sector over time, which provided an alternative method to present ETA and STA in a planview graphical user interface (P-GUI) display. Last, the literature showed the benefits of providing advisories to help controllers resolve problems that other elements of the TBID highlight in the sector. Because of the scope of our usability analysis, subsequent development focused on presenting particular elements of a TBID but did not include further development with advisories.

The first usability study examined differences between a T-GUI and a P-GUI, which included design elements identified from the literature review (i.e., color coding, timelines, and slot markers) and from an informal review with SMEs. We based the sample air traffic scenario on a Philadelphia TRACON final approach sector that included four entry points and three merge points. The usability study showed that the timeline presented by a T-GUI did not provide adequate information about the entry and merge points, and prior research showing the benefits of the timeline incorporated scenarios in which operators managed en route traffic. Subsequent development focused on using color coding, slot markers, and an exact presentation of time (i.e.,

fractions of minutes with an early/late [E/L] indicator to denote aircraft that were either early or late) in the datablock of the P-GUI display.

The second usability study included the development of a dynamic, low-fidelity P-GUI prototype that incorporated fractions of minutes, E/L indicators, color coding, and slot markers. We reviewed comments from six current Air Traffic Control Specialists (ATCS) and conducted statistical analyses of their questionnaire ratings (N = 4). Although we acknowledge the statistical pitfalls and limited generalizability of results based on such a small sample, our analyses indicated a preference for using color coding and slot markers as visuospatial representations of time. Color coding provided additional information by categorizing actionable aircraft and prioritizing where to act first, and the slot marker provided information about the difference between ETA and STA that was easy to process. Although the participants did see potential use for a literal representation of time (i.e., fractions of minutes and E/L indicators), this was not as useful as other elements, and they stated that providing too much time-based information on a display could clutter it with redundant information. Although there were limitations to our analyses, the findings suggest that the best method for displaying time-based information may be to not display time information at all; designing a system to use spatial and symbolic information that represents time-based information may be the most beneficial. To verify these findings, we recommend that the FAA conduct additional empirical research to directly compare and contrast different methodologies for the presentation of time-based information and to determine the effects of each methodology on ATCS performance, workload, and system efficiency.

Participants also provided additional comments about the prototype TBID elements. First, a TBID should not clutter a display with redundant information. Second, future iterations of TBID development should include advisories (e.g., speed advisories) to provide decision support. Third, a TBID needs to consider how to integrate time-based information into the datablock so as to not compete with the existing datablock design. Fourth, participants raised concerns about how algorithms of a decision-support system might impact the reliability of a TBID. We conclude the report by providing a table of design recommendations for TBID and by providing topics for future research.

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1. INTRODUCTION

With Next Generation Air Transportation System's (NextGen) increased emphasis on time-based flow management and four-dimensional trajectories, there is a growing need to understand the human factors and usability issues associated with NextGen time-based information and to present human factors guidance relevant to the design and display of time-based information. Several current and proposed NextGen systems present time-based information to support sequencing and spacing operations. Systems typically present this information as timelines (e.g., a vertical scale showing when each aircraft is estimated to arrive at a particular fix or runway). An example of the timeline display method is the timeline graphical user interface (T-GUI) of the Traffic Management Advisor (TMA) developed by NASA (Atkins, Brinton, & Walton, 2002; Hoang & Swenson, 1997; Robinson, Reynolds & Evans, 2010). NASA has proposed other time-based display methods such as *slot markers* as part of the Terminal Sequencing and Spacing (TSAS) program (Witzberger, Martin, Sharma & Robinson, 2015). Slot markers display a recommended location for each aircraft so that controllers can meet time-based metering assignments. In addition, previously proposed NextGen tools, such as the Relative Position Indicator (RPI), share many attributes with time-based systems and may inform the design and implementation of time-based systems (Atkins & Capozzi, 2011).

1.1 Purpose

The purpose of this research is to evaluate NextGen time-based information display (TBID) concepts and to examine standard practices for the display and use of time-based information on Terminal Radar Approach Control (TRACON) radar displays. The specific objectives of this research are:

- to research prior efforts to present time-based information in domains relevant to air traffic control (ATC),
- to develop and evaluate prototype methods for presenting time-based information in ATC, and
- to provide guidance and standard practices for presenting time-based information on NextGen ATC displays.

The Human Factors Branch (ANG-E25) at the FAA William J. Hughes Technical Center conducted research to examine TBID for the Human Factors Division (ANG-C1). We completed a literature review to assess previous work and develop an annotated bibliography (Fincannon, Racine, & Truitt, 2016). We worked with subject matter experts (SMEs) to develop prototypes and narrowed the scope of the research to address TRACON operations at the radar position.

There were two phases of usability analysis for prototype development. For the first usability analysis, we worked closely with two SMEs to develop five non-interactive prototypes. We used the first usability analysis to select a non-interactive prototype that we further developed into a dynamic, low-fidelity prototype. Six current Air Traffic Control Specialist (ATCS) participants observed the dynamic prototype in a second usability analysis. We used feedback from the two usability analyses and the annotated bibliography to provide recommendations to guide the design of TBIDs that we present in this technical report.

2. BACKGROUND

Numerous researchers have shown that time-based information is helpful in the National Airspace System (NAS). For example, research by Abbott (2009) found that strategic, time-based trajectories are more efficient in terminal airspace because they do not suffer from the operational disadvantages of tactical, constant spacing. Similarly, research has shown that implementing time-based metering can improve conflict resolution (Aweiss, Farrahi, Lauderdale, Thipphavong, & Lee, 2010). Given the benefits of time-based information, there is a need to understand how to best display this information to help air traffic controllers.

One method of presenting time-based information is the TSAS system, which provides controllers with time-based scheduling and precision spacing tools. Research by Thipphavong, Martin, Swenson, Lin, and Nguyen (2012) found that elements of TSAS can improve performance and reduce operator workload. Because of these findings, prior research with existing systems provided a strong foundation for identifying methods to display time-based information.

2.1 Color Coding and Attention

Color coding is an important tool to direct attention and help controllers identify solutions to potential air traffic conflicts. Early research by Davis, Erzberger, Green, and Nedell (1991) with the Final Approach Spacing Tool (FAST) provided useful information about the presentation of color. FAST is an automation tool that uses speed and heading advisories to assist controllers with sequencing and spacing. FAST used a projected path, displayed in orange, to indicate when controllers needed to have pilots change the speed of an aircraft. It also changed the color of a datablock to blue to indicate that the aircraft would need to turn and projected a recommendation for this path in blue. There were additional features of FAST that we review in subsequent sections, but the implementation of FAST resulted in several positive outcomes. Davis et al. found that controllers used more of the airspace to manage traffic, and the traffic had a shorter final approach path with FAST (i.e., approximately 18 nautical miles [NM] with the baseline versus 10–11 NM with FAST). FAST decreased inter-arrival spacing for time and distance, and increased the arrival capacity at an estimated rate of 4.6 aircraft per hour. Results of a questionnaire indicated that there was a reduction in: a) the self-reported workload, b) the number of speed and heading clearances, and c) mental workload. The benefits of FAST indicate that elements of this system deserve consideration and that color coding was a significant component of the design.

Subsequent research by Davis, Krzeczowski, and Bergh (1994) examined a FAST system that included: a) a route analyzer and trajectory synthesizer, b) a sequencer and scheduler, c) a conflict resolver, d) a runway allocator, and e) a controller interface. They found that the system improved the use of airspace and increased arrival rates without affecting controller acceptance. They also found that color coding helped controllers understand the interface. The findings of Davis et al (1991; 1994) indicate that TBIDs can use color coding to direct attention and prioritize solutions.

2.2 Timeline Displays

Timelines are also an important tool for displaying time-based information. Research with FAST by Davis et al. (1991) examined a number of time-based methods, which included a vertical timeline to provide scheduled time of arrivals (STAs) and estimated time of arrivals (ETAs) to help schedule and sequence aircraft. As mentioned in Section 2.1, there were a number of beneficial performance outcomes. Furthermore, controllers from the study reported that the timeline was useful in helping them with the task.

Another study with the Spot and Runway Departure Advisor (SARDA) system examined the use of advisories that included a timeline display (Jung et al., 2011). The SARDA advisories appeared in a vertical timeline and included sequencing, timing, takeoff, and arrival runway-crossing sequences. Findings from this study indicated that SARDA reduced average departure delay, number of aircraft stops, fuel consumption, and engine emissions. Overall, these findings indicate that designers of information displays can supplement a timeline display with advisories to benefit controllers.

It is important to note that the research by Davis et al. (1991) and Jung et al. (2011) focus on en route operations. In contrast, the scope of this study addresses operations in the TRACON. A central question of the first usability study in our analysis (see Section 3) addresses the generalizability of our findings.

2.3 Advisories

An important component of design that appears throughout the literature includes advisories to provide options and support for air traffic management (ATM). Erzberger and Tobias (1986) conducted a series of studies examining the impact of speed advisories on controller performance. One of their studies examined the impact of advisories with different mixes of 4D-equiped aircraft and unequipped aircraft. They compared three conditions in which either 0%, 25%, or 50% of the aircraft were 4D-equipped. Controllers reported the highest levels of workload with the 25% mix, and the impact of the advisories was strongest in the 25% mix condition. Findings indicated that advisories improved the transition of aircraft between sectors, reduced the number of adjustments to the subsequent flight path, and resulted in more consistent flight paths.

The FAST system (see sections 2.1 and 2.2) also included advisories (Davis et al., 1991). As previously mentioned, FAST is an automation tool that uses speed and heading advisories to assist controllers with sequencing and spacing aircraft. Davis et al. reported positive outcomes for operator performance and controller workload. In addition, controllers provided feedback that the advisories were timely and consistent with, or better than, their preferred course of action.

Subsequent research with FAST by Davis et al. (1997) examined advisories with live air traffic. This study focused on implementing Passive FAST (P-FAST) as a subset of the FAST system that studied the use of runway and sequencing advisories. Findings of this study indicated that the advisories could increase airport throughput and arrival rates. The advisories also improved performance by balancing runway traffic without impacting workload or taxi-in/taxi-out times.

Research with SARDA (see Section 2.2) by Jung et al. (2011) also examined the use of advisories. SARDA provided advisories to ground and local controllers in airport traffic control towers and could display the advisories on both a timeline and in the datablocks. The study evaluated the impact of SARDA by examining system performance in baseline conditions, conditions with advisories in the datablock, and conditions with advisories on the timeline. Displaying advisories in the datablock and in the timeline both improved efficiency compared to the baseline conditions.

Qualitative research also supports similar conclusions regarding the impact of advisories (Coppenbarger, Lanier, Sweet, & Dorsky, 2004). Coppenbarger et al. (2004) conducted a study with the En Route Descent Advisor (EDA), which computes advisories to help controllers deliver aircraft within a STA. The authors conducted interviews to assess the benefits of this tool and examine a number of design components, which included automation to resolve problems with an aircraft's trajectory. Findings indicated that EDA decision support tools should decrease workload, increase efficiency, help create solutions, and improve operations over manual methods.

2.4 Slot Markers

Slot markers are also relevant to the display of time-based information. A slot marker is a spatial representation of an aircraft's ideal location to meet a scheduling restraint (Witzberger et al., 2015). Research by Witzberger et al. (2015) examined TSAS tools (i.e., timeline, slot marker, early/late indicators, and advisories) under conditions of high- and low-arrival rates and different off-nominal events (e.g., transition from independent to dependent staggered operations, go-arounds, and pop-up aircraft). Controller ratings of the slot marker indicated that it was the most useful tool in the study.

Earlier research by de Muynck, Bos, Kuenz, and Törner (2012) examined similar issues with a study of ATM tools. The tools focused on concepts for time-based operations that researchers developed within the Environmentally Responsible Air Transport project. A time-based tool within the system used waypoints as a spatial representation of where aircraft should be located at a specific time. The researchers examined the tools with continuous decent operations and compared conditions that either did or did not include time-based tools. The study examined the success rate for continuous decent approaches and found that implementing time-based tools improved performance.

In another study of TSAS, Thipphavong et al. (2013) also found performance benefits of slot markers. The researchers conducted a human-in-the-loop (HITL) simulation under conditions of heavy traffic and included a comparison of conditions that either did or did not include TSAS tools. Conditions with the TSAS tools had: a) shorter flight paths, b) an increase in throughput of aircraft, c) higher adherence to performance-based flight paths, and d) less vectoring. The researchers also found that controllers used the slot markers more than the other TSAS tools (e.g., speed advisories) to complete the task. In addition to demonstrating the benefits of TSAS, Thipphavong et al. (2013) showed the importance of the slot marker as a preferred tool within TSAS.

Another study by Robinson, Thipphavong, and Johnson (2015) examined multiple components of TSAS. This HITL study was unique in that it compared baseline conditions to a gradual implementation of TSAS tools. These conditions included a baseline condition, a condition with TSAS scheduling that did not include slot markers or additional TSAS tools, a condition with TSAS scheduling and slot marker that did not include additional TSAS tools, and a condition with scheduling and a full set of TSAS tools. Regarding navigation performance in which aircraft followed procedures without vectoring, the conditions with optimal performance only included the conditions with slot markers. There was no difference between limited and full implementation of TSAS tools whenever the slot marker was present. Furthermore, controllers reported that the slot marker was the most useful controller-managed spacing tool.

3. USABILITY STUDY 1

We conducted an exploratory usability study to examine prototype methods and display concepts based on the literature review. We used the results from this exploratory usability study to inform further development of a dynamic, low-fidelity display prototype for analysis in the subsequent usability study.

3.1 Method

3.1.1 Participants

Two retired ATCSs participated as SMEs. One SME previously managed air traffic in a TRACON facility, and the other SME managed air traffic in an en route facility.

3.1.2 Air Traffic Scenario

We designed a static air traffic scenario to establish an operational context for the usability study. We based the traffic pattern on the final approach to runway 27L at Philadelphia International Airport (PHL). Aircraft entered the scenario from two points in the north and two points in the south, which resulted in three merge points in the sector (see Figure 1). The aircraft were never closer than 3 NM from one another to maintain standard separation. The air traffic scenario resulted in a static display with 34 aircraft in the sector. The air traffic scenario did not contain any heavy aircraft to simplify the development and presentation of the prototype display.

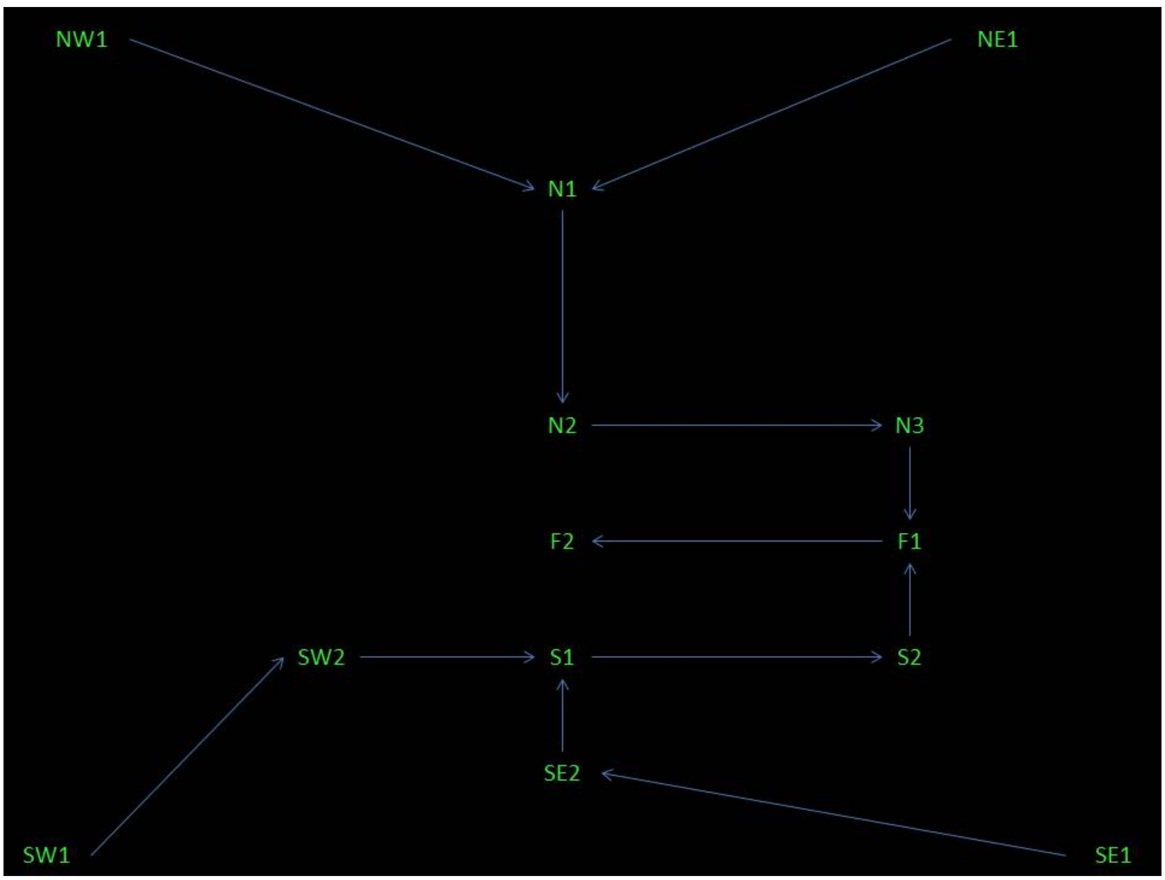

Figure 1. Air traffic scenario approach paths to runway 27L.
Note: Aircraft enter at points NW1, NE1, SW1, and SE1 and merge at points N1 and S1 for final approach at point F1. Point F2 indicates the threshold for runway 27L.
Arrows indicate the direction of traffic.

3.1.3 Prototype Display

We collaborated with the SMEs to develop five prototype displays (see Figures 2–10). One of the displays was a T-GUI and the other four displays were planview graphical user interfaces (P-GUIs). We began the prototype display development by discussing prior research in the context of TRACON operations and how TRACON operations differ from en route operations. We identified four relevant time-based information components of the prototype display design:

- fractions of minutes,
- early/late (E/L) indicators to identify aircraft that were either early (STA was earlier than ETA) or late (STA was later than ETA),
- slot markers, and
- color coding.

In this display, we adapted fractions of minutes as a component from previous designs of time-based information (Robinson et al., 2015; Thipphavong et al., 2013; Witzberger et al., 2015). The majority of those designs used 1-minute increments, but there were some systems that used tenths of minutes. The SMEs thought that more precise time information would be required to accomplish the task of managing air traffic to a specific STA. Therefore, we decided to display time information in fractions (tenths) of minutes.

We determined that E/L indicators were an important design element because previous displays of time-based information typically used a +/- indicator to show if an aircraft was either ahead or behind its STA (Robinson et al., 2015; Thipphavong et al., 2013; Witzberger et al., 2015). Some studies used +/- (Robinson et al., 2015; Witzberger et al., 2015), whereas other studies used E/L (Thipphavong et al., 2013). The SMEs thought the +/- indicators were confusing and could be interpreted incorrectly. For example, it was difficult to understand whether the + indicated that an aircraft was ahead of schedule or if it needed to increase speed because it was behind schedule. Therefore, we thought that controllers would find an E/L indicator easier to interpret. Current research on TSAS and information from other researchers (R. Bone, personal communication, July 20, 2016) led to our decision to use the E/L indicators. In addition, we decided to consider both color coding and slot markers as important elements of the prototype TBIDs based on the literature as presented in sections 2.1 and 2.2.

For early prototyping and assessment, we used a whiteboard to draw aircraft and their datablocks including the time-based information design elements. We then further developed the prototypes using Microsoft® PowerPoint®. The SMEs used the resulting display prototypes to provide feedback in the context of a busy TRACON final approach sector.

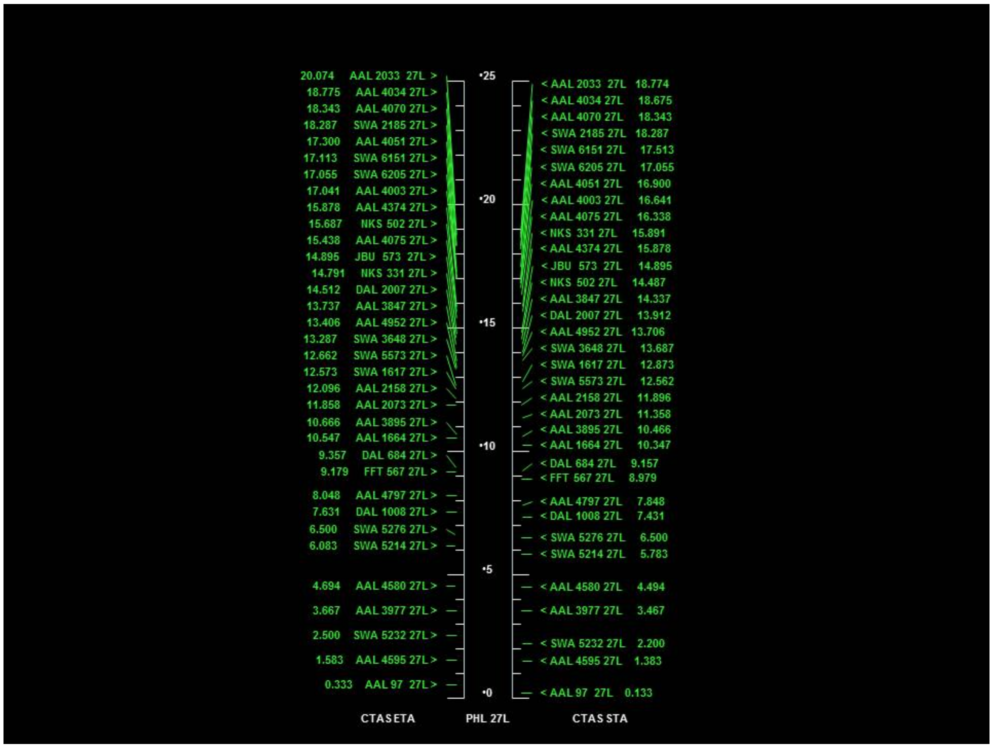

Figure 2. Prototype T-GUI display.

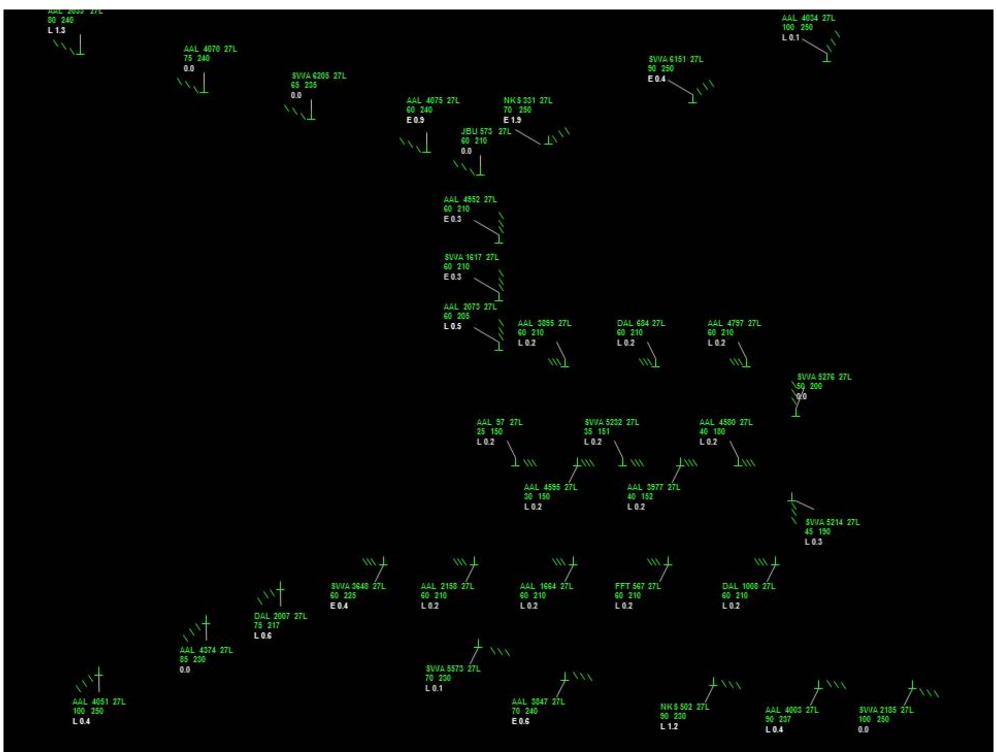

Figure 3. Prototype P-GUI display with E/L indicators and fractions of minutes.

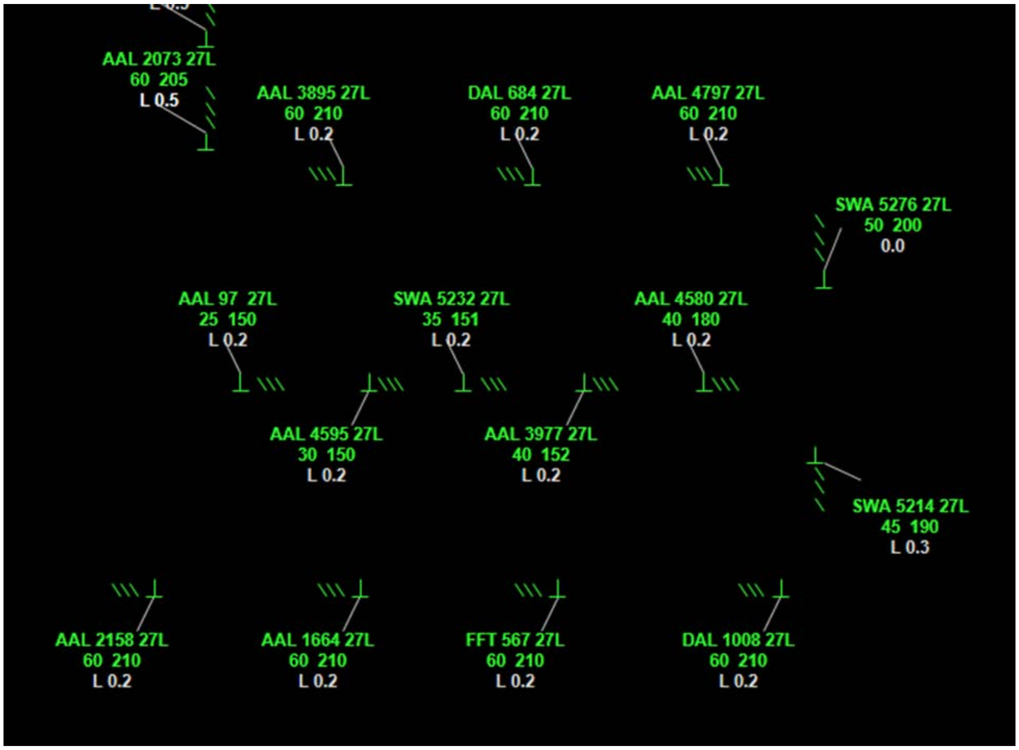

Figure 4. Close-up view of prototype P-GUI display with E/L indicators and fractions of minutes.

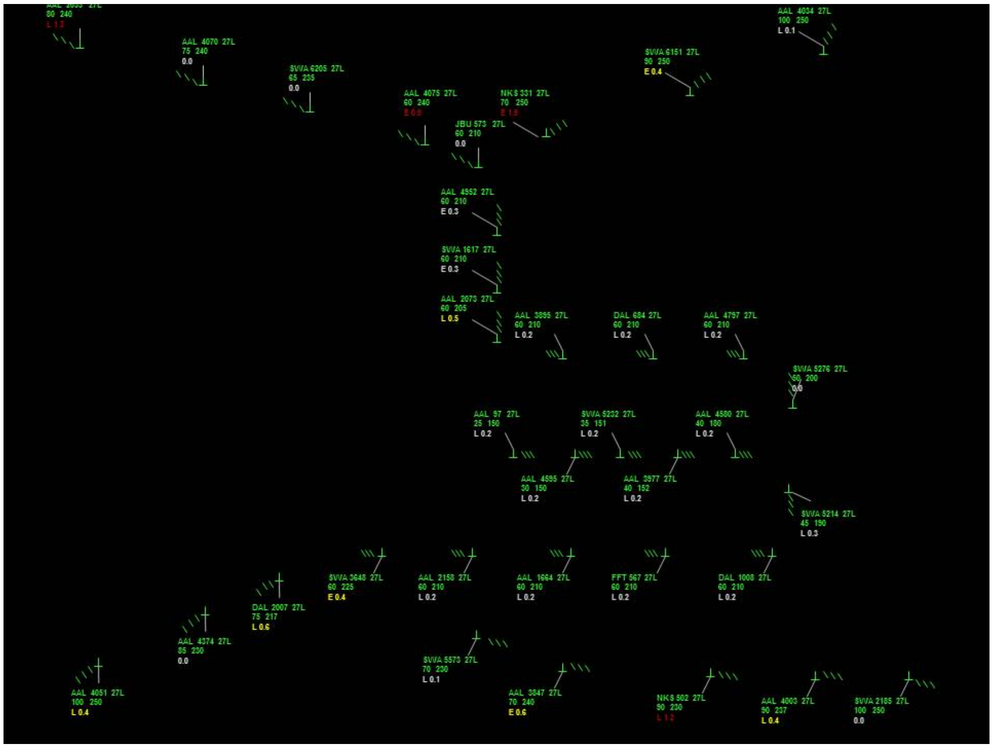

Figure 5. Prototype P-GUI display with E/L indicators, fractions of minutes, and color coding.

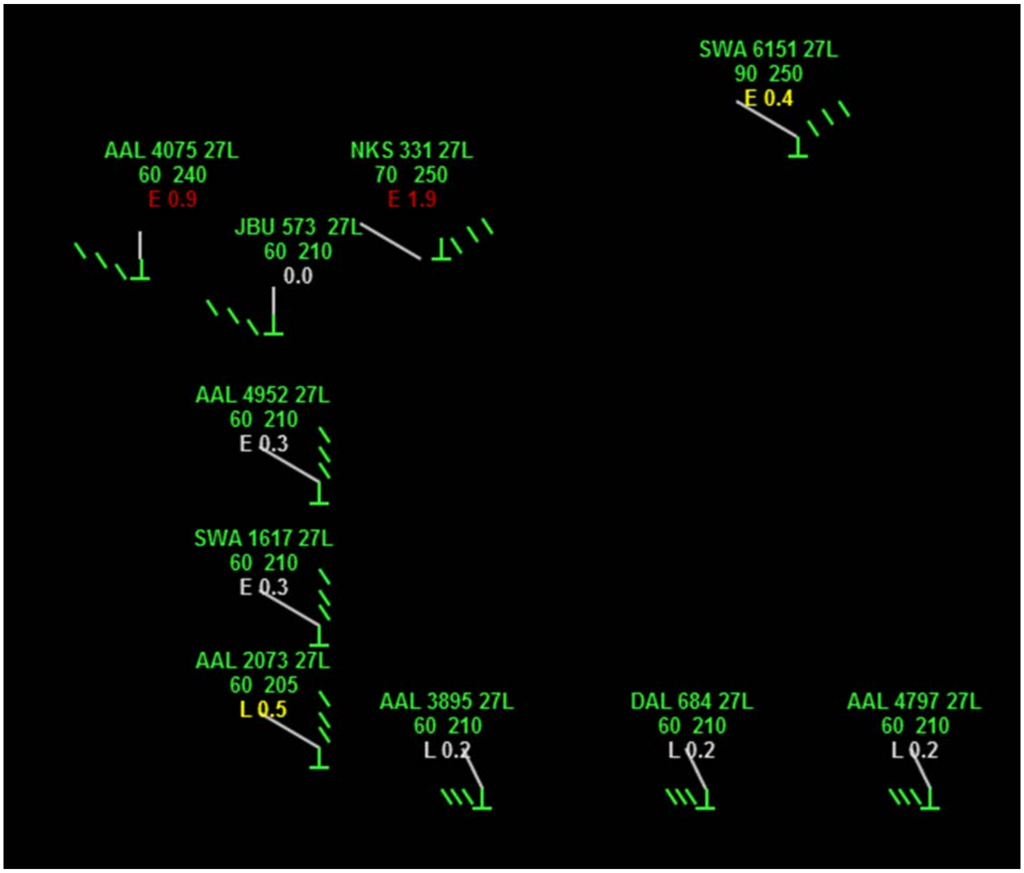

Figure 6. Close-up view of prototype P-GUI display with E/L indicators, fractions of minutes, and color coding.

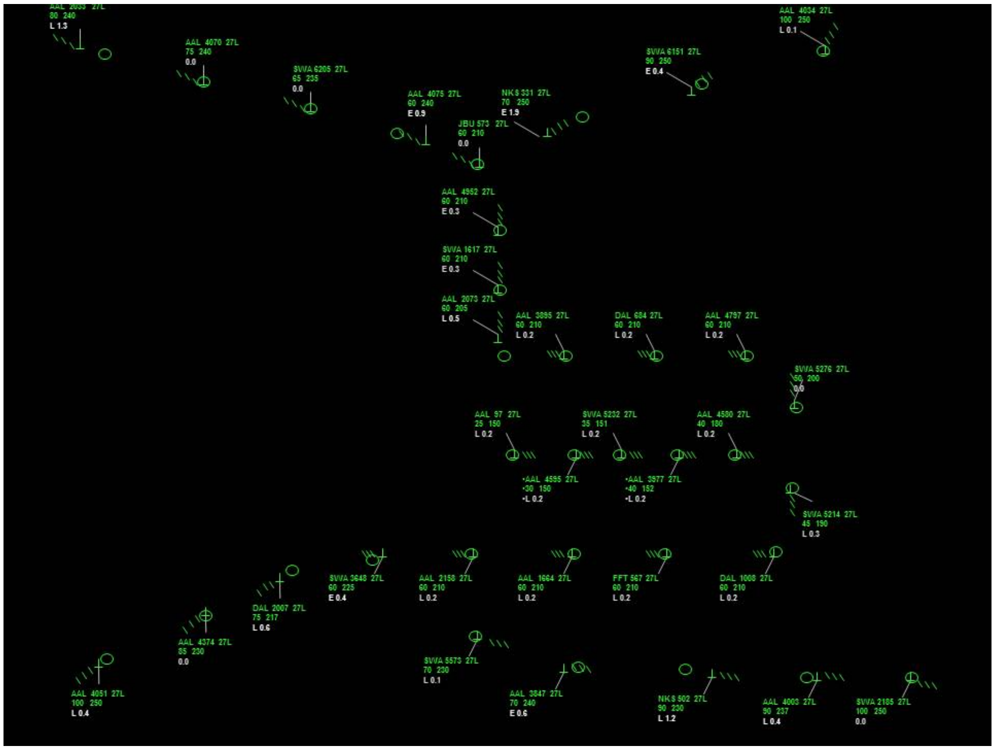

Figure 7. Prototype P-GUI display with E/L indicators, fractions of minutes, and slot markers.

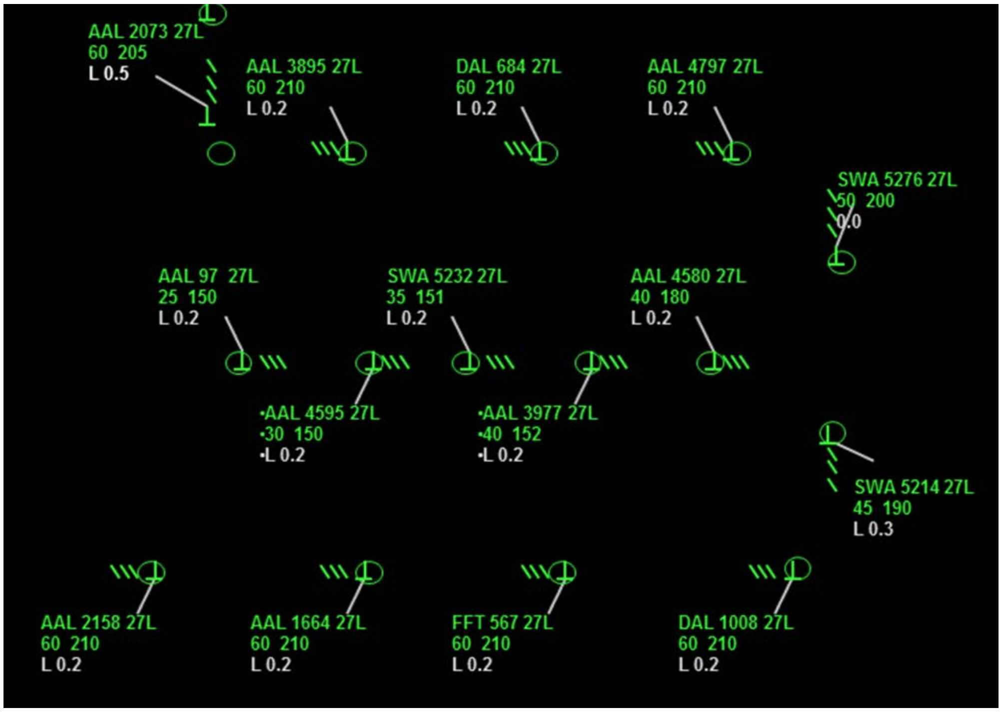

Figure 8. Close-up view of P-GUI display with E/L indicators, fractions of minutes, and slot markers.

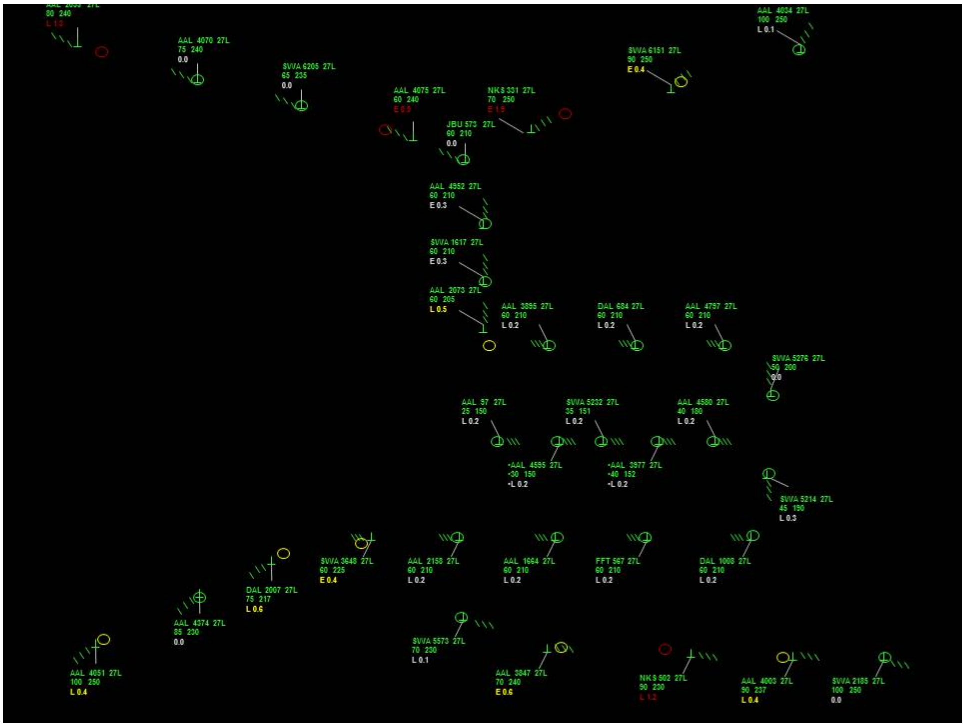

Figure 9. Prototype P-GUI display with E/L indicators, fractions of minutes, color coding, and slot markers.

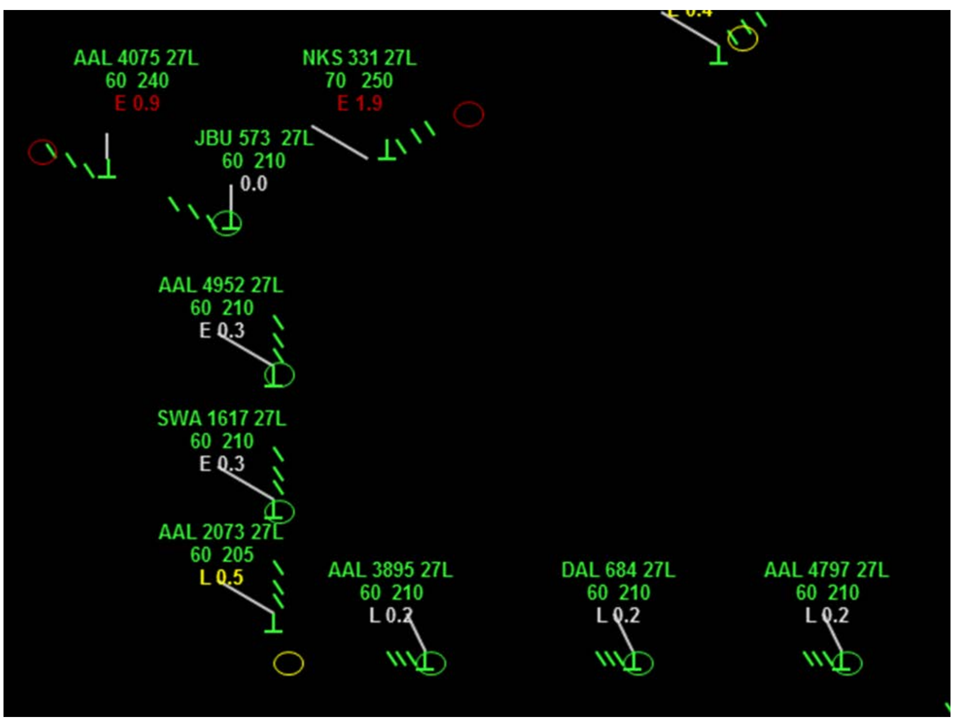

Figure 10. Close-up view of prototype P-GUI display with E/L indicators, fractions of minutes, colors coding, and slot markers.

3.2 Results

The SMEs identified several problems with using a T-GUI to present TBID information for managing TRACON traffic. The first problem involved finding aircraft in large lists of separated ETA and STA times. This primarily involves aircraft entering the sector from four different locations, in which each entry point corresponds to a unique path and schedule for aircraft. As Figure 11 illustrates, the display uses the ETA and STA to form two separate lists for the aircraft, and the display orders aircraft from all four entry points into each list. When differences between the ETA and STA emerge, the order of aircraft also differs between the lists, which make it difficult to identify scheduling discrepancies.

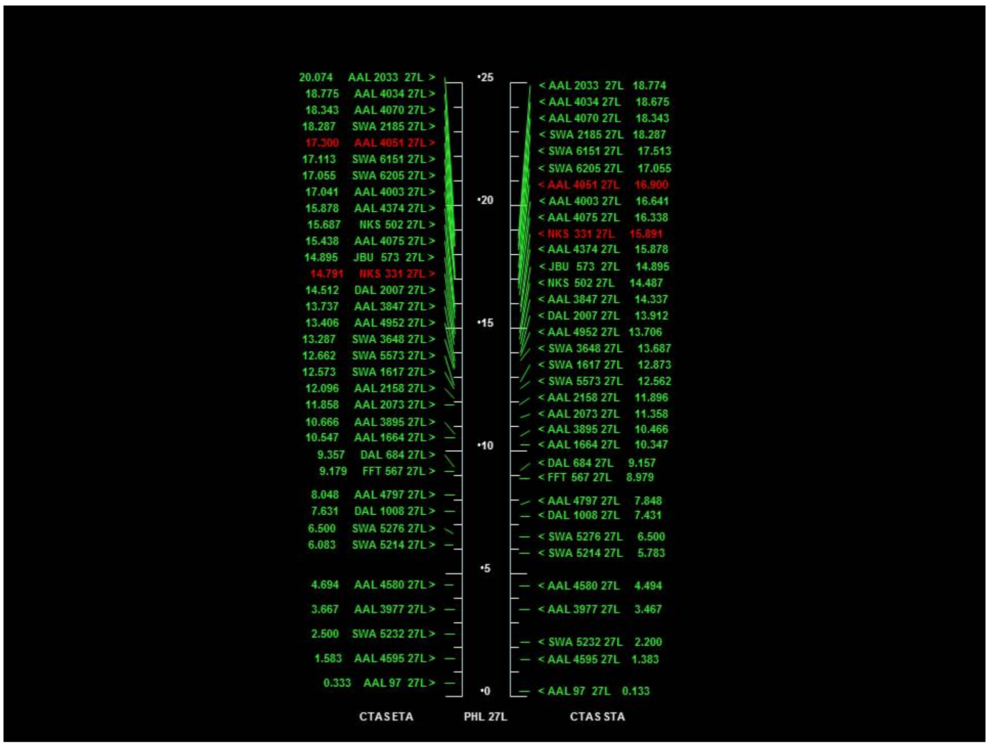

Figure 11. Tracking individual aircraft in a T-GUI display.

A second problem with the T-GUI involved tracking aircraft from a single entry point. As seen in Figure 12, the SMEs thought it would be difficult to track aircraft that entered the sector from a specific entry point. The SMEs noted that they must be able to identify aircraft separation issues shortly after the aircraft entered the sector and before the aircraft started to merge. The SMEs reported that tracking aircraft and resolving separation issues would be too difficult with a T-GUI display.

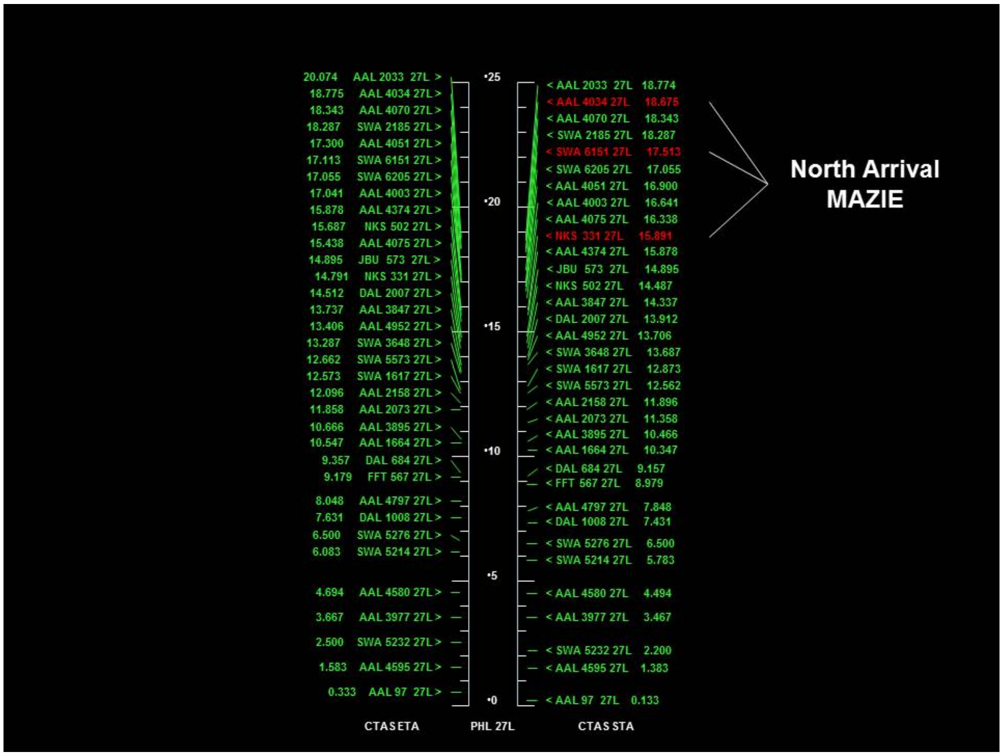

Figure 12. Tracking aircraft from one entry point in a TRACON sector with a T-GUI display.

Based on the problems that we identified with the T-GUI, we focused subsequent prototype designs on a P-GUI display that began with a simple display of time (see Figure 3). Other methods for displaying time used a +/- to indicate that aircraft were either early or late relative to their STA. But, as previously mentioned, the SMEs thought that the +/- indictors were confusing so they recommended we use an E/L to indicate if an aircraft was either early or late.

A second consideration from the P-GUI in Figure 3 was using fractions of minutes. In TRACON operations, our SMEs noted that aircraft can only be early or late by a maximum of 2 minutes because of the small amount of airspace and time available to either absorb or create a delay. If the aircraft are outside of this parameter, controllers would deny that aircraft entry into the sector because they would not be able to correct large discrepancies between ETA and STA within a busy and relatively small final approach sector. Furthermore, displaying time in whole minute increments would only give TRACON controllers five indicators of time (i.e., +2, +1, 0, -1, -2). The SMEs recommended that the display use fractions (tenths) of minutes to provide more accurate information about whether an aircraft was either increasing or decreasing the amount of time between its ETA and STA.

The SMEs also reported that the display of time in fractions of minutes as shown in Figure 3 made it easier to interpret time, but it would still be difficult to identify the most serious discrepancies between ETAs and STAs. Therefore, we decided to use color coding as shown in Figure 5 to direct the controller's attention to the most serious discrepancies. We used a simple color scheme in which yellow indicated that the difference between the ETA and STA was 0.3 to 0.6 minutes. Red indicated that the difference between the ETA and STA was 0.6 to 2.0 minutes. Color coding also provided controllers with a means to prioritize aircraft in need of immediate control action and helped to identify tolerable differences between ETAs and STAs.

Although the SMEs thought that color coding was useful, it did not help them identify a solution, which led to our incorporation of slot markers as shown in Figure 7. The SMEs thought that slot markers would support controllers by providing a visual indication of where an aircraft needed to be in the sector. The SMEs thought that a slot marker would provide a simple way for controllers to resolve any discrepancy between an aircraft's ETA and STA. We first attempted to provide slot markers without color coding, but the SMEs said that color coding was still necessary to direct attention to the most serious problems and to help them identify aircraft that needed immediate control action. As a result of all of the SME feedback, our final iteration of the prototype TBID included E/L indicators, fractions of minutes, color coding, and slot markers (see Figure 9).

3.3 Discussion

It is important to address the SME preference to use a P-GUI over a T-GUI. Although prior research showed the use of timelines in a TBID (Davis et al., 1991; Jung et al., 2011), our initial usability analysis showed several problems with using a T-GUI at a TRACON radar position. In periods of heavy traffic, it is difficult to track individual aircraft in separate ETA and STA lists. Furthermore, if controllers are trying to separate aircraft before they merge for the final approach, a timeline makes it difficult to determine which aircraft are entering from the same point in the sector. Prior research illustrating a preference for timelines appears to originate from tasks that require operators to manage en route traffic or traffic flow in a more strategic way. Our initial usability analysis highlighted unique features of the TRACON radar position and resulted in a different set of preferences that supported a more tactical operation. Our findings are consistent with research by Walton, Quinn, and Atkins (2002) that showed an operator preference for a map-based format in TRACON displays.

During the course of the prototype display development, we identified three major design components for the display of time-based information. The first component involved a direct display of the difference between aircraft ETAs and STAs, and this was the most direct representation of time on a P-GUI. The second component involved using slot markers. The slot markers provided controllers with a visuospatial display of where aircraft should be located according to automated scheduling. The third display component involved the use of color coding. Color coding provided a course categorization of tolerable deviations and actionable items, and it also directed attention to the most important deviations between ETAs and STAs.

4. USABILITY STUDY 2

We conducted a second usability study based on the results from the first usability study. After considering the results of the first usability study, we developed a dynamic low-fidelity prototype display that included E/L indicators, fractions of minutes, color coding, and slot markers. We used the same TRACON final approach airspace configuration that we developed for the first usability study and then asked current field controllers to evaluate the display.

4.1 Method

4.1.1 Participants

Six ATCSs participated in this study. Three of the participants were bargaining unit employees from the National Air Traffic Controllers Association (NATCA), and three of the participants were supervisory ATCSs. Five of the participants were male, and one participant was female. All of the participants were from a Level 11 or Level 12 TRACON facility. Only four of the six participants completed the Background Questionnaire (Appendix B), and they had a mean age of 38.75 years (*SD* = 8.54) and ranged from 32 to 51 years of age. The participants were experienced working as an ATCS (*M* = 17.71 years, *SD* = 8.36 years), and their experience ranged from 8.83 to 28.50 years. On average, they worked as a Certified Professional Controller (CPC) for 13.19 years (*SD* = 8.36 years) with a range of 5.42 to 25.00 years, and had actively controlled traffic in a TRACON facility for an average of 12.60 years (*SD* = 8.30) with a range of 7.42 to 25.00 years. Most of the controllers had significant experience with the Standard Terminal Automation Replacement System (STARS) (*M* = 6.81 years, *SD* = 4.33 years) ranging from 0.58 to 10.42 years. On a 10-point scale, all of the participants rated their current skill as a CPC as 8 (M = 8.0, *SD* = 0.0). The participants rated their current level of stress as moderate on average (*M* = 4.25, *SD* = 2.22) with a range of 2 to 7 on a 10-point scale, and their level of motivation to participate in the study as relatively high (*M* = 8.00, *SD* = 1.41), ranging from 7 to 10.

4.1.2 Apparatus

We used a standard personal computer to generate the prototype TBID and air traffic scenario. We used WebEx (Cisco Systems) to present the prototype display and air traffic scenario to the participants.

4.1.2.1 Prototype Display

The prototype display provided a simplified STARS-like datablock including aircraft call sign, altitude, ground speed, and aircraft type. Ground speed and aircraft type timeshared a field in the second line of the datablock. The datablock also provided color-coded text to indicate if the aircraft's ETA was ahead (early) or behind (late) its STA. Figures 13 and 14 show an example screenshot of the prototype display. The third line of each datablock displayed an E or L indicator with a time. Aircraft that were early showed an "E" in the datablock, and aircraft that were late showed an "L" in the datablock with the amount of time (in tenths of a minute) that the aircraft was early or late. Aircraft that were early or late by 0.1 to 0.3 minutes displayed the appropriate indicator and time with white text and a green slot marker. Aircraft that were early or late by more than 0.3 to 0.6 minutes displayed the appropriate indicator and time with yellow text and yellow slot marker. Aircraft that were early or late by more than 0.6 to 2.0 minutes displayed the appropriate indicator and time with red text and red slot marker. Aircraft that were on time (i.e., ETA differed from the STA by less than 0.1 minutes) did not display any time-based information in the datablock other than a green slot marker.

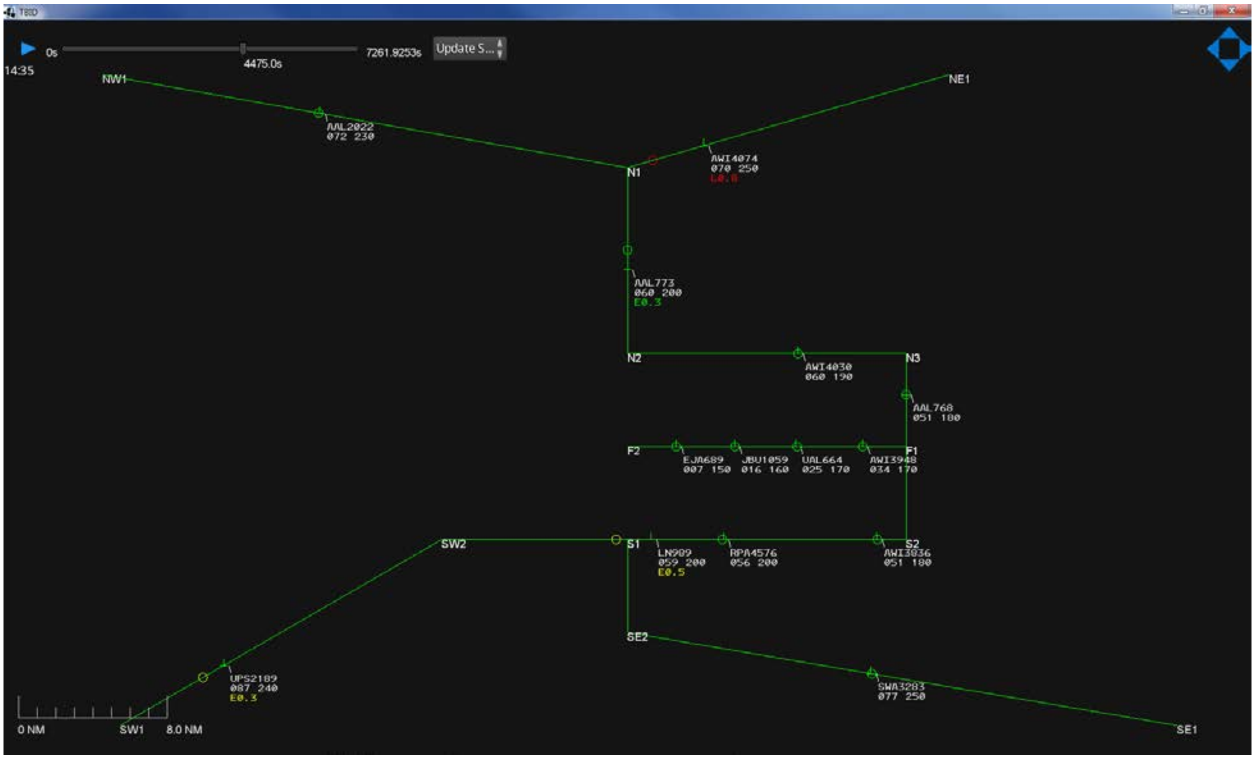

Figure 13. Sample screenshot of the prototype display that includes color coding, slot markers, E/L indicators, and fractions of minutes.

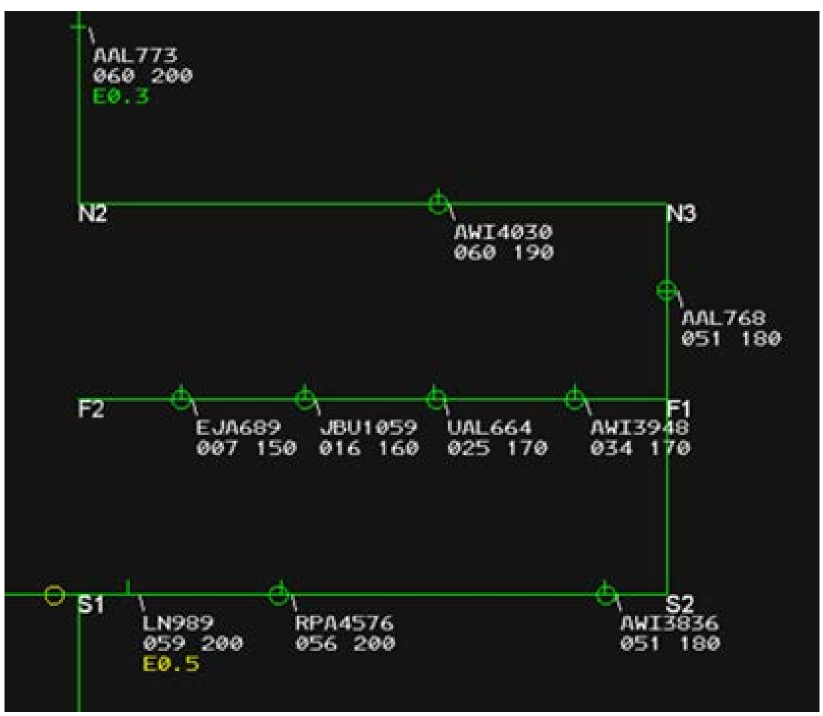

Figure 14. Close-up view of sample screenshot of the prototype display that includes color coding, slot markers, E/L indicators, and fractions of minutes.

The prototype display included a number of display controls that enabled the researchers to conduct the user evaluation. The display controls allowed researchers to play and pause the air traffic scenario, jump to any time within the air traffic scenario, and zoom and re-center the display. Although these controls appeared on the display, they were not part of the TBID concepts that the participants evaluated.

4.1.2.2 Air Traffic Scenario

We designed an air traffic scenario based on the traffic pattern for the final approach to runway 27L at PHL. Aircraft were scheduled to arrive at the runway at no less than 1.2-minute intervals and were randomly spawned at one of four corner posts (entry fixes). The ETA for spawned aircraft randomly deviated from their STA by 0 to 2 minutes, and aircraft were never generated closer than 3 NM from one another to maintain standard separation. The air traffic scenario resulted in a maximum runway arrival rate of 42 aircraft per hour. The air traffic scenario did not contain any heavy aircraft to simplify the development and presentation of the prototype display.

4.1.3 Procedure

We conducted the user evaluation online via a WebEx meeting, and the evaluation procedure lasted approximately 2 hours. Prior to the user evaluation, we sent each participant a packet that contained a brief set of initial instructions, Informed Consent Statement (ICS) (Appendix A), Background Questionnaire (Appendix B), and Post-Scenario Questionnaire (PSQ) (Appendix C). The participants' names did not appear on the Background Questionnaire or on the PSQ. Instead, the researchers coded each Background Questionnaire and PSQ with a participant number. We instructed the participants to not complete any of the forms until instructed to do so during the user evaluation. The instructions in the participant packet also provided directions on how to join the WebEx meeting.

On the day of the user evaluation, the researchers and participants joined the WebEx meeting. Once everyone was online, the researchers introduced the project by presenting the research objectives and background information. The researchers then instructed the participants to read and sign the ICS with a witness. After completing the ICS, the participants completed the Background Questionnaire. The researchers then provided specific instructions for the user evaluation.

The researchers noted the fidelity of the prototype display and its limitations. The researchers emphasized that the primary goal of the research was to examine the prototype TBID concepts at hand and not the fidelity of the display. The researchers began the evaluation of the TBID concepts by showing a static (i.e., paused) image of the prototype display. The researchers then explained each element of the TBID, including the slot markers, color coding, E/L indicators, and time information. Once the participants understood the display elements, the researchers started the dynamic air traffic scenario and let the participants observe the TBID behavior. The researchers used a free-form discussion with an open-ended question-and-answer protocol to elicit the participants' feedback. The researchers continued to use the prototype TBID to supplement discussions and to review particular air traffic situations or display conditions. Researchers, with an air traffic SME, took written notes of the participants' verbal responses. The SME also provided technical information to answer the participants' questions when needed.

After reviewing the prototype TBID, participants completed the PSQ. Once the researchers ensured that the participants did not have any more questions or feedback about the TBID concepts, the researchers instructed the participants to place their ICS in an envelope and their Background Questionnaire and PSQ in a second envelope, and then mail the envelopes back to the researchers.

4.2 Results

This section provides a summary of the quantitative analyses and the participants' comments from the PSQ. We conducted a two-tailed, independent single sample *t*-test to compare the responses to the rating scale mid-point for items that used a Likert rating scale. For items that had a 10-point rating scale, we used 5.5 as the midpoint. For items that used a 9-point rating scale, we used 5 as the midpoint. We only controlled for error rate per comparison, but used a two-tailed *t*-test as a more conservative approach given our small sample size ($N = 4$). For PSQ items that required a yes/no response, we coded a "yes" response as 1, and a "no" response as 0. For relative comparisons (see Section 4.2.4), we used a one-way repeated measures Analysis of Variance (ANOVA). We then tested significant omnibus effects using the Bonferroni post-hoc procedure (Howell, 2002). All statistical tests used a criterion of $p \leq 0.05$ for significant effects. We also calculated effect sizes for all statistically significant effects using either partial eta-squared (η_p^2) for ANOVAs or Cohen's *d* for *t*-tests (Cohen 1988, 1992)[1]. For all descriptive statistics, we rounded means (*M*) and standard deviations (*SD*) to two decimal points, and we rounded the results of inferential statistics to three decimal points.

Only four of the six participants completed and returned the PSQ. This small sample size limited the statistical power of the inferential data analyses in the following subsections, and our analyses could only identify significant differences that had large effect sizes. We did write down comments from all six participants during the usability study, which enabled us to discuss their feedback. The participant comments in this section include those we recorded both during the usability study and those recorded from the PSQ. Tables of summary statistics are shown in Appendix E.

4.2.1 Ratings for Fractions of Minutes and Time

Participants rated the effect of using fractions of minutes on their ability to identify which aircraft required intervention first (see PSQ Item 3). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 1 to 7 ($M = 4.00$; $SD = 2.58$). There was a high degree of variability in these ratings, and there was not a statistically significant difference from a neutral rating of 5, $t(3) = 0.775$, $p = 0.495$.

The participants' comments about fractions of minutes were generally negative. Two participants indicated that fractions of minutes require extra, unnecessary thinking to convert to seconds. They also stated that this unnecessary thinking can be especially problematic when managing a high number of aircraft.

Participants rated the effect of using fractions of minutes on their ability to notice when the difference between the ETA and STA was changing (see PSQ Item 4). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 3 to 5 ($M = 4.25$; *SD*

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[1] Cohen (1988, 1992) describes the use of Cohen's *d* and partial eta-squared to evaluate effect size. For both measures, a value of 0.20 is considered a small effect, 0.50 is considered a medium effect, and 0.80 or greater is considered a large effect.

= 0.96). These ratings were negative to neutral, but they were not significantly different from a neutral rating of 5, $t(3) = 1.567$, $p = 0.215$.

In addition to noting that fractions of minutes required too much time to understand, there were three suggestions for improving the system's design to help distinguish ETA from STA. The first type simply suggested using seconds to make it faster to assess the situation. The second comment focused on using other components of the prototype instead of displaying fractions of minutes. One participant commented that the color of the slot marker was a sufficient indicator of time to distinguish differences between an aircraft's ETA and STA. Another comment focused on design elements that were not in the prototype, which included a preference to simply have an advisory provide a suggestion for addressing differences between ETA and STA.

We asked the participants to rate how fractions of minutes impacted their ability to determine which aircraft were on schedule (see PSQ Item 5). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 5 to 8 ($M = 6.00$; $SD = 1.41$). These ratings ranged from no effect to a positive effect, but they were not significantly different from a neutral rating of 5, $t(3) = 1.414$, $p = 0.252$.

Comments regarding the use of fractions of minutes varied across participants for Item 5. One participant simply reported that the information was clear. In contrast, another participant restated a preference for using seconds over fractions of minutes because fractions of minutes required too much time to process.

For Item 5, there were a variety of comments about how automation schedules arrival aircraft in the sector. It is also important to note that one participant brought up a question about integration with other systems that provide information to create the schedule. The participant reported that the schedule of arrivals was not as important as making sure the aircraft fit reliably within the sequence, and that the schedule for this prototype needs to ensure that fit. Although the display did provide a schedule of arrivals, and the participants could interpret that information, it could have been clearer. Even if the display presented this message clearly, the algorithms behind the system need to be reliable enough for controllers to trust the information that it provides.

We asked the participants to rate the effort needed to interpret fractions of minutes in the datablock (see PSQ Item 6). On a scale of 1 (very low) to 10 (very high), ratings ranged from 7 to 9 ($M = 8.50$; $SD = 1.00$). All of these ratings indicate a high level of effort, and the mean rating was significantly higher than a central point of 5.5, $t(3) = 6.000$, $p = 0.009$, $d = 3.000$.

The participants' comments about effort were generally negative. Participants said that they could interpret fractions of minutes, but it was unnecessarily complex and cumbersome during periods of high traffic. Again, participants stated a preference to use seconds over fractions of minutes to improve the display of time-based information.

We asked the participants to rate the effort needed to interpret the E/L indicators in the datablock (see PSQ Item 7). On a scale of 1 (very low) to 10 (very high), ratings ranged from 1 to 5 ($M = 2.50$; $SD = 1.91$). These rating were low, but they were not significantly lower than the central point of 5.5, $t(3) = 3.133$, $p = 0.052$.

Although the participants' comments about fractions of minutes were generally negative, participants stated that E/L indicators were easier to interpret. One participant said that this portion of the display was easy to interpret but recommended using two different colors to represent E/L indicators. The problem with this design component extended to its importance in the context of other design elements. One participant stated that the E/L indicators introduced unnecessary clutter into the display, and that the slot marker and color coding provided all of the necessary information.

We asked the participants if they would prefer the ability to toggle the time information on and off (see PSQ Item 8). All of the participants said they would prefer to have a toggle option. Participants commented on the need for options to accommodate personal preferences. One participant stated that the need to display time-based information could change over the course of the task and indicated a preference to possibly use it on the feeder, while avoiding it on the final approach.

Comments recorded from the observation focused on three major themes. First, the participants stated that presenting time as a fraction of a minute was problematic. The participants stated that it required too much thought and time to convert this information to seconds. Instead of presenting a fraction of a minute, controllers said that they preferred this TBID element to use a combination of minutes and seconds.

Second, the participants said they thought that displaying fractions of minutes was useful, but this usefulness was not consistent over time. The controllers said that fractions of minutes were most useful outside of 20 NM from the final approach, where it helped controllers understand whether things were getting better or worse over time. Within 20 NM of the final approach, the participants said that they felt that fractions of minutes were not useful. Because of the changing usefulness over time, the participants felt it was necessary to have the ability to toggle the time indicator on and off.

Third, the participants said that they did not have any difficulty with understanding the meaning of E/L indicators. However, like fractions of minutes, the usefulness of the E/L indicators was not consistent over time. The indicators were most useful when aircraft first entered the sector but were less useful after the first observation. For this reason, the participants stated that the E/L indicator was low-priority information, and they expressed an interest in toggling it on and off in the display.

4.2.2 Ratings for Color Coding

The participants rated the effect that color coding had on their ability to identify which aircraft required intervention first (see PSQ Item 9). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 6 to 9 ($M = 7.50$; $SD = 1.29$). The ratings were all positive, and the mean rating was significantly greater than a neutral rating of 5, $t(3) = 3.873$, $p = 0.030$, $d = 1.936$. One participant said that color coding was the only indicator needed for the display, but recommended a speed advisory to address problems with aircraft being early or late. Another participant stated that color coding was useful for directing attention to the datablock and wanted to use additional color coding to distinguish aircraft that were early from aircraft that were late.

The participants rated the effect that color coding had on their ability to notice when the difference between the ETA and STA was changing (see PSQ Item 10). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 5 to 9 ($M = 7.00$; $SD = 1.63$). The ratings were generally positive, but they were not significantly greater than a neutral rating of 5, $t(3) = 2.449$, $p = 0.092$. The only participant comments stated that color coding was clear and beneficial for the display of time-based information.

The participants rated how color coding impacted their ability to determine which aircraft were on schedule (see PSQ Item 11). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 7 to 9 (M = 7.50; SD = 1.00). Ratings were all positive and significantly greater than a neutral rating of 5, $t(3) = 5.000$, $p = 0.015$, $d = 2.500$. The participants stated that color coding was an excellent concept that directed attention to the datablock and that it was easy to process.

We asked the participants to rate the effort needed to interpret color coding in the datablock (see PSQ Item 12). On a scale of 1 (very low) to 10 (very high), ratings ranged from 1 to 2 (M = 1.50; SD = 0.58). Participants stated again that the color coding was clear and that they liked the color coding. The ratings were very low, and the mean rating was significantly lower than the central point of 5.5, $t(3) = 13.856$, $p = 0.001$, $d = 6.928$.

We asked the participants if they would prefer the ability to toggle the color coding on and off (see PSQ Item 13). The three participants commented that toggling information such as color coding on and off was desirable because it provided them with options for what information they displayed. Two participants stated that display options are typically better than no options and mentioned that some people may prefer not to use color coding at all. One participant disagreed with a preference to toggle color coding on and off. This participant thought that it was important to have color coding to direct attention and stated that removing color coding might result in overlooking important details.

During the observation of the prototype display, the participants stated a strong preference for using color coding and overall their comments regarding color coding were positive. They said that color coding was a fast and effective method to direct attention. They also thought that color coding was a good method for differentiating and prioritizing aircraft that required control action.

4.2.3 Ratings of the Slot Marker

The participants rated the effect that the location of the slot marker had on their ability to identify which aircraft required intervention first (see PSQ Item 14). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 5 to 7 (M = 6.25; SD = 0.96). Ratings were generally positive, but there was no significant difference from a neutral rating of 5, $t(3) = 2.611$, $p = 0.080$. One participant stated that the slot marker information was clear, but another participant stated that color coding was more important than the slot marker.

The participants rated the effect that the location of the slot marker had on their ability to notice when the difference between the ETA and STA was changing (see PSQ Item 15). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 6 to 8 (M = 7.00; SD = 0.82). All ratings were positive and the mean rating was significantly greater than the neutral rating of 5, $t(3) = 4.899$, $p = 0.016$, $d = 2.449$. One participant stated that changing differences between the ETA and STA were clear. Another participant stated that using the slot marker and color coding together was excellent.

The participants rated how the location of the slot marker impacted their ability to determine which aircraft were on schedule (see PSQ Item 16). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 6 to 8 (M = 7.25; SD = 0.96). The ratings were positive and significantly greater than the neutral rating of 5, $t(3) = 4.700$, $p = 0.018$, $d = 2.350$. The participants expressed a preference for the slot marker and stated that the slot marker was easy to understand. One participant noted the use of a slot marker, but said that it was less important than color coding. One participant was concerned about the integration of scheduling systems and noted the importance of ensuring that any display of time-based information must provide the appropriate arrival sequence.

We asked the participants to rate the effort needed to interpret the location of the slot marker in the datablock (see PSQ Item 17). On a scale of 1 (very low) to 10 (very high), ratings ranged from 1 to 8 ($M = 3.25$; $SD = 3.20$) and there was no significant difference from the central point of 5.5, $t(3) = 1.406$, $p = 0.255$. The participants stated that they could clearly see the slot marker and that it was easy to understand.

We asked the participants if they ever associated a slot marker with the wrong aircraft (see PSQ Item 18). None of the participants indicated that they associated a slot marker with the wrong aircraft. However, two participants indicated that it might be possible to associate a slot marker with the wrong aircraft with heavier traffic or a combination of early and late aircraft next to each other in the arrival stream.

We asked the participants if they would prefer the ability to toggle the slot markers on and off (see PSQ Item 19). All four or the participants that responded to the PSQ said they would prefer to have a toggle option. Again, the participants indicated that the ability to toggle information on and off was important to accommodate personal preferences. One of the participants listed a preference to not observe slot markers during the final approach.

During observation of the prototype TBID, we recorded comments from the participants that indicated a mixed utility of slot markers. The participants stated that slot markers provided constant updates about where the aircraft needed to be located over time. The slot markers also provided a means to ensure de-confliction of merging traffic streams, which aids with sequencing aircraft to the final approach. Some participants thought that slot markers would help with managing wake turbulence during final approach, but others did not want to see slot markers at all during the final approach. Overall, the participants favored the ability to toggle slot markers on and off. Some of the participants thought that the slot marker was too small and that other aircraft could obscure a slot marker. Future research should consider a larger slot marker and general sizing in relation to other elements of the display.

4.2.4 Relative Comparisons

During the observation of the prototype TBID, we asked the participants to rank their preference for the design elements in this prototype. They stated that the design element with the most utility was color coding. They stated that the slot marker had the next highest ranking of utility. The participants ranked fractions of minutes at the lowest level of utility and stated that improving the system by using seconds instead of fractions of minutes would not change this ranking. The participants' ratings of design elements from the PSQ generally coincide with the comments that we recorded during the observation of the prototype TBID.

We conducted additional analyses of the participants' ratings from the PSQ to examine the relative ratings for the design elements and to determine which elements would be most useful for the display and use of time-based information. Although the E/L indicators provided information about whether an aircraft was on schedule or not, the other design elements (i.e., fractions of minutes, color coding, and slot markers) provided more refined and actionable information that assisted the controller with reducing the difference between the ETA and STA for each aircraft.

For all the design components, we asked the participants to rate their ability to identify which aircraft required intervention first (see PSQ Items 3, 9, and 14). Figure 15 provides a summary of their ratings. Ratings for color coding ($M = 7.50$; $SD = 1.29$) and the slot marker ($M = 6.25$; $SD = 0.96$) tended to be higher than participants' ratings for fractions of minutes ($M = 4.00$; $SD =$

2.58). However, these differences were not statistically significant, $F(2, 6) = 3.744$, $p = 0.088$, $\eta_p^2 = 0.555$.

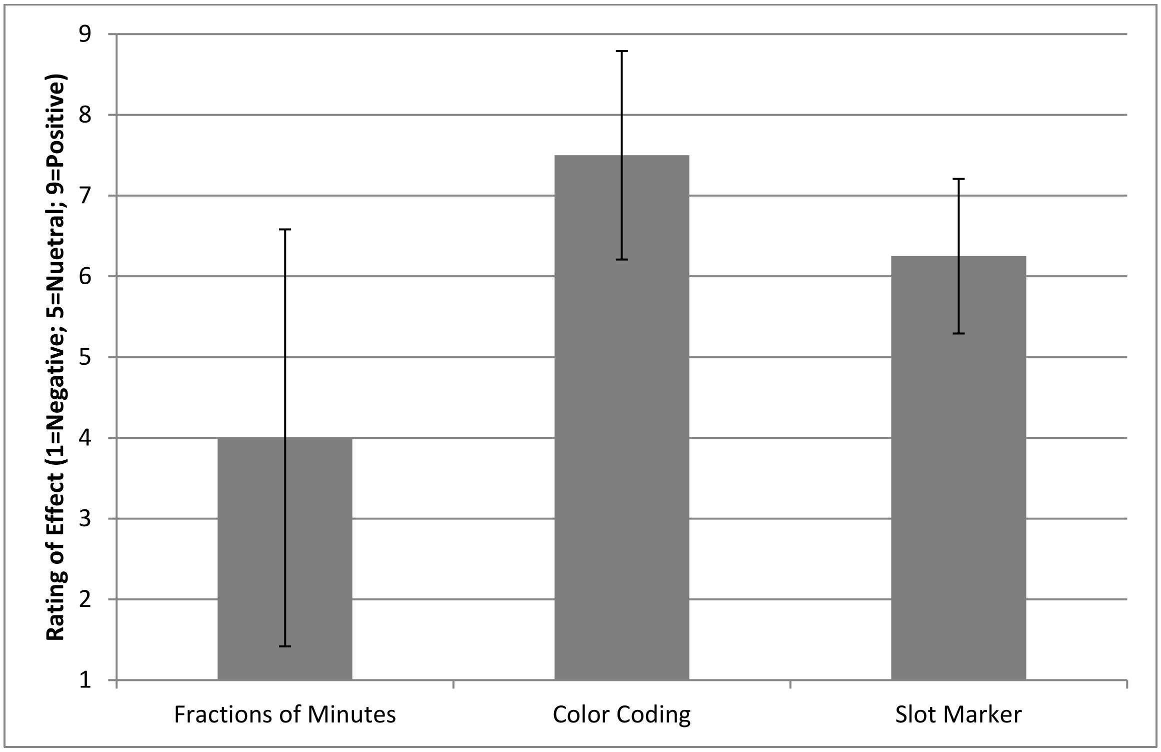

Figure 15. Ratings of design components on ability to identify which aircraft required intervention first.

For all the design components, we asked the participants to rate their ability to notice when the difference between the ETA and STA was changing (see PSQ Items 4, 10, and 15). Figure 16 provides a summary of these ratings. Ratings for color coding ($M = 7.00$; $SD = 1.63$) and the slot marker ($M = 7.00$; $SD = 0.82$) indicated a positive effect, with the same average rating for both design elements. Ratings indicated that fractions of minutes ($M = 4.25$; $SD = 0.96$) had a negative impact on the participants' ability to identify which aircraft required intervention first, which ranked this element as having the lowest degree of utility on this dimension. The ANOVA indicated that there was a statistically significant difference between these ratings, $F(2, 6) = 15.783$, $p = 0.004$, $\eta_p^2 = 0.840$. A post-hoc analysis with a Bonferroni correction indicated that ratings of color coding ($p = 0.008$) and the slot marker ($p = 0.008$) were both significantly greater than ratings of fractions of minutes. There was no difference between ratings of color coding and slot markers on this item ($p = 1.000$).

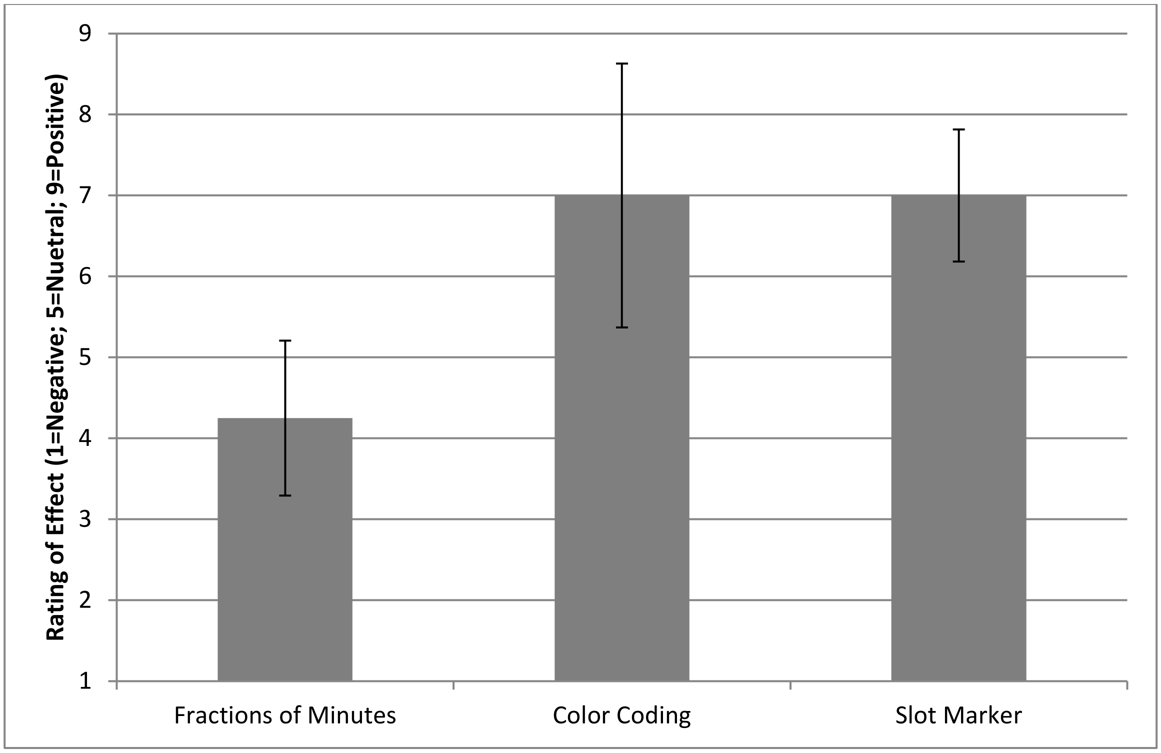

Figure 46. Ratings of design components on ability to notice when the difference between the ETA and STA was changing.

For all the design components, we asked participants to rate their ability to determine which aircraft were on schedule (see PSQ Items 5, 11, and 16). Figure 17 provides a summary of these ratings. The average rating for all three design elements indicated a positive effect on the participants' ability to notice when the difference between ETA and STA was changing. Ratings for color coding (M = 7.50; SD = 1.00), the slot marker (M = 7.25; SD = 0.96), and fractions of minutes (M = 6.00; SD = 1.41) were above the midpoint. The ANOVA did not find any statistically significant differences between these ratings, $F(2, 6) = 1.755$, $p = 0.251$, $\eta_p^2 = 0.369$.

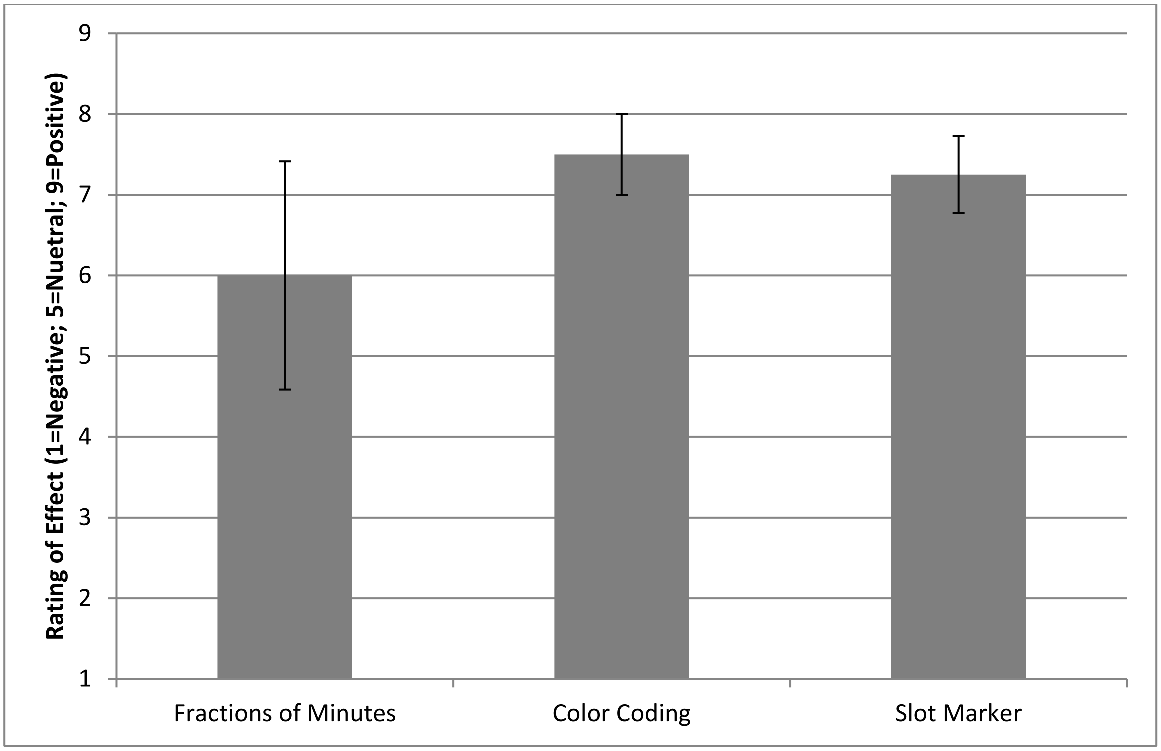

Figure 17. Ratings of design components on ability to determine which aircraft were on schedule.

For all the design components, we asked participants to rate the effort needed to interpret each element in the datablock (see PSQ Items 6, 12, and 17). Figure 18 provides a summary of these ratings, in which higher ratings indicate a greater degree of effort to interpret each component. Color coding (M = 1.50; SD = 0.58) was the easiest design element for participants to interpret. Ratings of the slot marker (M = 3.25; SD = 3.20) indicated that it was easy to interpret, but it was more difficult to interpret than color coding. Ratings for fractions of minutes (M = 8.50; SD = 1.00) indicated that this design element was difficult for the participants to interpret. The ANOVA indicated that there was a statistically significant difference between these ratings, $F(2, 6) = 11.443$, $p = 0.009$, $\eta p^2 = 0.792$. A post-hoc analysis with a Bonferroni correction indicated that ratings of color coding ($p = 0.011$) and the slot marker ($p = 0.041$) were both significantly greater than ratings of fractions of minutes, but the difference between ratings of color coding and slot markers was not significantly different ($p = 0.883$).

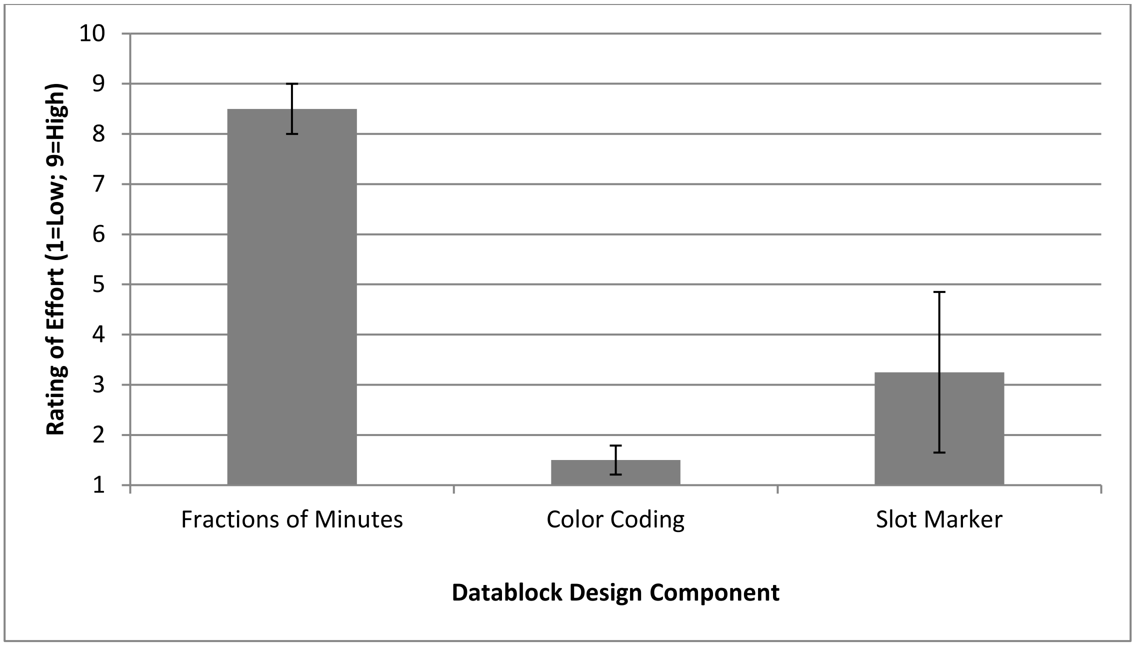

Figure 185. Ratings of design components on effort needed to interpret in the datablock.

Overall, the participants reported that color coding and slot markers were the most useful design elements and they were the easiest to interpret. Conversely, the participants rated fractions of minutes as the least useful, difficult to interpret, and thought that the use of fractions of minutes may have a negative effect on their ability to control traffic.

4.2.5 Ratings of Controller Effort and Workload, Safety and Efficiency

We asked the participants about their level of effort to determine whether aircraft were on schedule (see PSQ Item 1). On a scale of 1 (very low) to 10 (very high), all participants provided ratings of either 2 or 3 (M = 2.50; SD = 0.58). A one sample t-test indicated that the mean rating was significantly lower than a center point of 5.5, $t(3) = 10.392$, $p = 0.002$, $d = 5.196$. The participants' ratings were consistently low, indicating that determining whether aircraft were on schedule or not was a low-effort task.

The participants' comments regarding the level of effort needed to determine whether aircraft were on schedule or not were generally positive and focused on building upon their preferred design elements. In addition to providing positive comments about color coding, one participant suggested using color coding as a foundation to provide more information (e.g., red for late, yellow for early) to help controllers assess aircraft conformance to STAs. Other positive comments stated that the scheduling task was clear and that it did not require much effort. The participants also provided negative comments that focused explicitly on reporting time in fractions of minutes. One participant stated a preference for using the exact number of seconds that aircraft deviated from their STA, as opposed to fractions of minutes, to improve the display of time-based information.

We asked the participants to rate the effort needed to identify which aircraft required intervention first (see PSQ Item 2). On a scale of 1 (very low) to 10 (very high), ratings ranged from 3 to 7 (M = 4.75; SD = 1.71). These ratings were generally low, but because of the high variability of the ratings, the mean rating was not significantly different from a central point of 5.5, $t(3) = 0.878$, $p = 0.444$.

Comments from the general question about the effort needed to identify which aircraft needed intervention first involved three types of responses. The first response focused on identifying problems with the existing design. In particular, the participants commented on the difficulty of interpreting fractions of minutes. The second type of response involved highlighting potential problems based on existing systems in the field. Out of concern for integration with existing systems, one participant suggested ensuring that the slot markers guarantee separation standards. The third type of comment focused on providing design recommendations to include systems that would help with ATM. Specifically, the participants recommended providing aircraft speed advisories that would assist them in achieving the desired arrival schedule.

We asked participants about the effect of the prototype's display concepts and whether using them at their facility would impact air traffic safety (see PSQ Item 20). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, all four of the participants gave a rating of 5 ($M = 5.00$; $SD = 0.00$). The ratings were all neutral, so they did not perceive that the display concepts would have an impact on the safety of air traffic. The participant comments indicated that there was a concern about shifting from distance-based separation techniques to time-based separation techniques. One participant stated that controllers were likely to rely on distance-based techniques, especially within 20 miles of the airport. Another participant reiterated this point by commenting on the culture change that would shift focus to time-based techniques. One participant also noted that relying on slot markers to separate aircraft could lead to potential hazards, but the participant did not provide additional details. Based on comments from the other participants, this concern could have been related to trust of a system that may not separate traffic appropriately.

We asked the participants about the effect of the prototype time-based display concepts and whether using them at their facility would impact air traffic efficiency (see PSQ Item 21). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 5 to 8 ($M = 6.25$; $SD = 1.50$). The ratings were generally positive but not significantly different from a neutral rating of 5, $t(3) = 1.667$, $p = 0.194$. The participants' ratings regarding air traffic efficiency indicated that there were multiple perspectives regarding the overall prototype design. One participant stated that the prototype display would have a positive impact on efficiency and that there was utility when aircraft first entered the airspace. Two of the participants noted that the current form of the prototype display was too basic to impact efficiency or that the prototype display would shift focus from efficiency to thinking about whether aircraft are on time or not. One participant noted conditions of light traffic in which slowing early aircraft would decrease efficiency. Although decreased efficiency could occur if arrival scheduling was flawed, our prototype display maximized efficiency to the arrival runway by scheduling aircraft to arrive on an optimal schedule.

We asked the participants about the effect of the prototype display concepts and whether using them at their facility would impact ATCS workload (see PSQ Item 22). On a scale of 1 (negative effect) to 9 (positive effect) with 5 representing no effect, ratings ranged from 2 to 5 ($M = 3.25$; $SD = 1.50$). The ratings were generally negative indicating that overall the prototype time-based display concepts may increase ATCS workload, but the mean rating was not significantly different from a neutral rating of 5, $t(3) = 2.333$, $p = 0.102$. The participants expressed several concerns about the prototype display concepts. One participant stated that the prototype display simply contained too much information to look at and think about. Another participant noted that controllers might focus more on slot markers than efficiency. However, we must point out that the intent of arrival aircraft scheduling and slot markers is to maximize efficiency. One participant noted the utility of the prototype display as long as the ability to display it was optional. One participant said that controllers could potentially assign control instructions to match the slot marker when nothing was needed prior, but another controller thought the prototype display would provide a benefit as long as the slot markers ensured separation.

We provided an open-ended question asking what time-based information should be added to the TRACON ATCS radar display (see PSQ Item 23). The participants reiterated that the use of color coding was good and that the slot marker and information about any discrepancy between the ETA and STA (in whole seconds, not fractions of minutes) provided information about how to make appropriate adjustments. Other responses focused on ways to improve the system such as speed advisories, time to a fix, and assistance resolving conflict points.

Finally, we asked the participants if they had any additional comments (see PSQ Item 24). One participant stated that the prototype display concepts had the potential to be very useful in the NAS, and one participant reiterated a preference for using color coding. One controller recommended that we add speed advisories. The participants also noted a number of concerns. One participant stated that one display design approach will not always be useful and that the benefits to some operations and configurations will not manifest in other circumstances. Another participant stated that a time-based separation technique is a major change from current techniques, and this could make it difficult for controllers to adjust. One controller also asked about whether the prototype display accounted for compression in scheduling aircraft to the arrival runway. Specifically, the participant noted that when extra space is needed on the final approach, the utility of the time-based separation concept will significantly diminish. Although we understand the participant's concern regarding compression on final approach, the prototype display concepts were only intended to display time-based information and were not designed to create a new scheduling system. Therefore, any negative effects of scheduling would not arise from the display of time-based information itself.

4.3 Discussion

Overall, the participants thought that the prototype TBID provided useful time-based information. The participants' ratings on the PSQ indicated that the prototype display would not have an effect on air traffic safety, but it may affect ATCS workload and efficiency.

The participants expressed a consistent preference for the use of color coding. Color coding directed the participants' attention to the most important issues and provided a visual indication of deviations between ETA and STA. If an aircraft was early or late, the color coding alerted the participants to the problem as soon as it entered the airspace. Second, they noted that color coding provided information about actionable categories. Red and yellow color coding informed the participants about deviations from the STA that required immediate action, and it also prioritized aircraft that needed immediate action. An added benefit of using green color coding for the slot marker was that it showed a tolerable deviation from the STA that did not require any intervention by controllers. Other components of the prototype TBID provided information about time, but they did not provide information about tolerable deviations between the ETA and STA. Overall, color coding provided a course presentation of time-based information that corresponded to controller actions for resolving discrepancies between ETAs and STAs, and the additional meaning behind the color coding added benefit to the prototype TBID.

The participants also liked how the prototype TBID used slot markers. The spatial, non-numeric representation of time was easy to understand. If a slot marker was in front of or behind the aircraft, it provided information about whether that aircraft was early or late, and the magnitude of difference between the aircraft and the slot marker provided sufficient information about the difference between the ETA and STA. Slot markers not only provided controllers with information about deviations in a schedule, but they also provided information about whether the situation was getting better or worse. The participants could process this information quickly, and they said that it provided what they needed to assess the situation. In addition to highlighting preferences for the slot marker, we identified areas for potential improvement and concern. First, participants noted that controllers could possibly confuse the slot marker of one aircraft for the slot marker of another aircraft. We did not observe any confusion in our usability study, but the participants stated that that a combination of heavier traffic and the right mix of early and late aircraft could cause confusion. The participants' suggested that TBID methodologies may not be universally effective across different types and combinations of airspace and air traffic. Second, some participants noted that the slot markers were too small and that aircraft could obscure them in the display. If the FAA determines to use slot markers, they should conduct research into optimal slot marker design. Future research should also examine how slot marker design may interact with different types of airspace and air traffic.

Although the E/L indicator was easy to understand, it did not provide the participants with any additional benefits. The participants could quickly gather the same information provided by the E/L indicator from the color coding and slot markers. Therefore, the participants thought that the E/L indicator was redundant information that cluttered the display.

The participants did not like the use of fractions of minutes to indicate time because they thought it would increase their cognitive workload. Translating fractions of minutes into seconds and then having to determine required speed adjustments was too difficult and would add to controllers' cognitive workload unnecessarily, especially during periods of high traffic. Although providing time in whole seconds would improve workload over providing fractions of seconds, having the automation system calculate speed advisories would provide the most benefit to controllers while keeping their cognitive workload at a manageable level. Furthermore, the exact presentation of time was redundant with the visuospatial presentation of time embodied in the color coding and slot markers.

The participants expressed a strong preference for the use of symbolic and spatial representations of time (i.e., color coding and slot marker) over literal indicators of time (i.e., E/L indicator and fractions of minutes). The slot marker provided information about the difference between ETA and STA as the direct indicators of time, but it was easier to process than literal indicators of time. Color coding provided the participants with more information by categorizing actionable aircraft and prioritizing where they needed to act first. Designing a system to use spatial and symbolic information that represents time-based information may be the most parsimonious and useful method for the display of time-based information. When controlling air traffic using time-based separation techniques, controllers prefer to have information that they can readily act upon. Therefore, the best method for displaying time-based information may be to not display time information at all.

Regardless of the methodology that we choose to display time-based information, there is a need to accommodate personal preferences. The participants noted that the use of TBID designs could change over the course of the task. For example, one feature that is helpful during the feeder sector might not be useful at the final approach sector. Therefore, we recommend that TBID designs include a toggle feature to turn individual components on and off.

The participants' verbal and written responses indicated that they had concerns about systems that simultaneously showed some misunderstandings about the purpose of the prototype TBID concepts. The prototype TBID that we demonstrated for the participants was simply a user interface, and it did not perform any automation or scheduling functions. Components of En Route Automation Modernization (ERAM), Terminal Automation Replacement System (TAMR), or some other automation system would provide the necessary scheduling functions. However, the participants noted that the FAA must properly design and integrate any new decision support tools or display concepts with existing systems. For example, facilities that use Automated Terminal Proximity Alert (ATPA) could receive confusing or contradictory information if new TBID concepts are not designed and integrated properly. The participants noted that TBFM provides a 1-minute buffer around a slot marker, so there were differences between existing systems and the prototype TBID that they observed in our usability study. New systems or tools that use time-based information must be integrated with existing systems to ensure that they do not provide inconsistent or misleading information.

In addition to system integration issues, the participants' verbal and written responses indicated potential issues with reliability and trust in automation. The participants expressed a number of concerns about how the prototype TBID might integrate into existing systems. Specifically, they expressed concerns about how the algorithms of underlying systems might impact the reliability of information that they observe on the display. If controllers question the quality and reliability of the information that they observe, these issues have the potential to impact the degree to which they trust and rely on the system. Parasuraman and Riley (1997) described a model of how operators use automation inappropriately. Their model includes scenarios in which operators distrust reliable automation (i.e., disuse) and overly rely on unreliable automation (i.e., misuse). Parasuraman and Riley argued that poor use of automation stems from a variety of factors including trust in automation that inappropriately matches the reliability of the system. Further research should explore this relationship between system reliability and trust in automation in the context of a TBID.

Regardless of the method that we chose to display time-based information, the FAA must consider the overall approach to datablock design and how to integrate time-based information into the existing datablock design. For example, some facilities are currently displaying ATPA information on the third line of the STARS scratchpad and this information would compete with the time-based information that the participants observed in the prototype TBID.

The participants also expressed some skepticism regarding the use of time-based separation techniques. Although en route controllers have been using time-based separation techniques for some time, it is relatively unfamiliar to TRACON controllers who are used to distance-based separation techniques. One participant stated that controllers did not need time-based information and would prefer to use distance-based spacing. The participants that acknowledged a need for time-based information said that they did not need it for the final approach control position and that the arrival sequence is set on the downwind leg of the approach. The participants cared more about distance than time on the final approach. Some of the participants' concerns about the prototype TBID (e.g., negative effects due to compression on final approach, reduced efficiency) would actually be alleviated by time-based separation. Lee and See (2004) presented a model of trust in automation whereby trust affects reliance on a system. Furthermore, they argued that one can conceptualize trust as a function of beliefs, attitudes, intentions, and behaviors, and training interventions that focus on these underlying components of trust and can improve reliance on a system. Therefore, we believe that additional controller training on new TBIDs and any underlying automation would improve controllers' trust and acceptance of time-based separation techniques.

5. RECOMMENDATIONS AND CONLUDING REMARKS

The goal of this project was to provide recommendations that support the display of time-based information at a TRACON radar position. We reviewed relevant literature and conducted two usability studies. We provide a set of design recommendations for the display of time-based information in Table 1.

Table 1. Table of Design Recommendations for Time-Based Information Display

Recommendation	Comments
Use color coding to illustrate categories of difference between STA and ETA.	Color coding directed attention and provided a course representation of time.
Use color coding to inform controllers about necessary actions.	Color coding showed a need to resolve a problem (e.g., red and yellow) or that there were no problems in the airspace.
Use color coding to prioritize actions in the airspace.	Color coding showed which aircraft needed immediate action.
Use slot markers to indicate where aircraft should be located at the moment.	Slot markers provided visuospatial indictors of differences between ETAs and STAs.
Use whole minutes and seconds to provide a literal indication of time.	Minutes with seconds were easier to interpret than fractions of minutes, but there was a preference for other TBID methods.
Use E/L indicator as a literal indication of whether the aircraft is early or late.	E/L indicators were less confusing than +/- indicators, but there was a preference for other TBID methods.
Use visuospatial instead of literal representations of time.	The usability study showed a preference for color coding and slot markers; minutes/seconds and E/L indicators were least useful.
Provide users with the ability to toggle information on/off.	The location of aircraft in the TRACON affected the utility of time-based information.
Provide actionable advisories.	It was not sufficient to only provide time-based information; advisories would have provided decision support and reduced cognitive workload.
Do not clutter the display with redundant time-based information.	Providing too much information distracted controllers and made it more difficult to assess problems.
For TBID, use P-GUIs for TRACON options and T-GUIs for en route operations.	SMEs noted P-GUIs and T-GUIs support different control strategies that are necessary to manage TRACON and en route traffic.

In addition to these recommendations, we also identified the following areas for future research:

- Research that examines differences between direct versus visuospatial representations of time-based information;
- Research to examine the utility of design recommendations (e.g., slot marker) across different types of airspace and traffic;
- Research that examines different methods to display recommended TBID features (e.g., the size of slot markers);
- Research to understand how controller information needs change over time (e.g., feeder versus final approach) and how TBID can support these task demands;
- Research that examines how differences between TRACON and en route operations lead to different design requirements for TBIDs (e.g., utility of the P-GUI for TRACON and T-GUI for en route); and
- Research that examines the impact of training interventions on trust in, and reliance on, time-based information.

In summation, NextGen systems present time-based information to support sequencing and spacing operations, and there is a need to understand how NextGen TBIDs can provide relevant guidance. This project provided a review of previous research and conducted analyses with SMEs to develop a stronger understanding of relevant issues. We used the results of the usability studies to provide design recommendations and to identify potential areas of future research.

References

Abbott, T. (2009). A brief history of airborne self-spacing concepts (NASA/CR–2009-215695). Hampton, VA: Langley Research Center.

Atkins, S., Brinton, C., & Walton, D. (2002). *Functionalities, displays, and concept of use for the Surface Management System* [ATC]. Proceedings from the 21st Digital Avionics Systems Conference, 1, 1D6-1–1D6-12. DOI: 10.1109/DASC.2002.1067903

Atkins, S., & Capozzi, B. (2011). *Relative Position Indicator for merging mixed RNAV and vectored arrival traffic.* Proceedings from the IEEE/AIAA 30th Digital Avionics Systems Conference, Seattle, WA.

Aweiss, A. S., Farrahi, A. H., Lauderdale, T. A., Thipphavong, A. S., & Lee, C. H. (2010). *Analysis of a Real-Time Separation Assurance System with integrated time-in-trail spacing.* Proceedings from the 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, 9387. DOI: 10.2514/6.2010-9387

Bone, R. (2016, July 20). [Presentation of current TSAS research by MITRE to Time-Based Information Display Research Team at the William J. Hughes Technical Center]. Atlantic City International Airport, NJ.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Cohen, J. (1992). Statistics a power primer. *Psychology Bulletin, 112,* 155–159.

Coppenbarger, R. A., Lanier, R., Sweet, D., & Dorsky, S. (2004). *Design and development of the En route Descent Advisor (EDA) for conflict-free arrival metering.* Proceedings from the AIAA Guidance, Navigation, and Control Conference. DOI: 10.2514/6.2004-4875

Davis, T. J., Erzberger, H., Green, S. M., & Nedell, W. (1991). Design and evaluation of an Air Traffic Control final approach spacing tool. Journal of Guidance, Control, and Dynamics, 14(4), 848–854. DOI: 10.2514/3.20721

Davis, T. J., Isaacson, D. R., Robinson III, J. E., Den Braven, W., Lee, K. K., & Sanford, B. (1997, June). *Operational test results of the passive final approach spacing tool.* Proceedings from the Eighth IFAC Symposium on Transportation Systems, Chania, Greece. ISBN: 0080429319

Davis, T. J., Krzeczowski, K. J., & Bergh, C. (1994, September). *The final approach spacing tool.* Paper presented at the 13th IFAC Symposium on Automatic Control in Aerospace, Palo Alto, California. Abstract retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.31.9318&rep=rep1&type=pdf

de Muynck, R. J., Bos, T., Kuenz, A., & Törner, S. (2012, September). *Implementing time-based CDA operations in a medium-high density ATM environment.* Paper presented at the 28th International Congress on the Aeronautical Sciences. Abstract retrieved from http://www.icas.org/ICAS_ARCHIVE/ICAS2012/PAPERS/017.PDF

Erzberger, H., & Tobias, L. (1986). A time-based concept for Terminal-area traffic management (NASA-TM-88243). Moffett Field, CA: NASA Ames Research Center.

Fincannon, T., Racine, N., & Truitt, T., (2016). *Human Factors Guidance for the Display of Time-Based Information on Air Traffic Control Systems.* Atlantic City International Airport, NJ: Federal Aviation Administration William J. Hughes Technical Center.

Hoang, T., & Swenson, H. N. (1997). *The challenges of field testing the Traffic Management Advisor (TMA) in an Operational Air Traffic Control Facility* (NASA-TM-112211). Moffett Field, CA: NASA Ames Research Center.

Howell, D. (2002). *Statistical methods for psychology*. Pacific Grove, CA: Wadsworth Group.

Jung, Y., Hoang, T., Montoya, J., Gupta, G., Malik, W., Tobias, L., & Wang, H. (2011, June). *Performance evaluation of a Surface Traffic Management Tool for Dallas-Fort Worth International Airport.* Paper presented at the Ninth USA/Europe Air Traffic Management Research and Development Seminar (pp. 1–10). Abstract retrieved from http://atmseminarus.org/seminarContent/seminar9/papers/92-Jung-Final-Paper-4-8-11.pdf

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors, 46(1)*, 50-80.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors, 39(2)*, 230-253.

Robinson, M., Reynolds, H. D., & Evans, J. E. (2010). *Traffic Management Advisor (TMA) weather integration* (Project Report ATC-364). Lexington, MA: MIT Lincoln Laboratory.

Robinson, J.E., Thipphavong, J., & Johnson, W. (2015). *Enabling performance-based navigation arrivals: Development and simulation testing of the Terminal Sequencing and Spacing System.* Proceedings from the 11th USA/Europe Air Traffic Management Research and Development Seminar (ATM2015).

Thipphavong, J., Jung, J., Swenson, H., Martin, L. K., Lin, M., & Nguyen, J. (2013). *Evaluation of the Terminal Sequencing and Spacing System for performance-based navigation arrivals.* Proceedings from the 32nd IEEE/AIAA Digital Avionics Systems Conference, 1A2-1–1A2-16. DOI: 10.1109/DASC.2013.6712503

Thipphavong, J., Martin, L., Swenson, H., Lin, P., & Nguyen, J. (2012, July). *Evaluation of the Terminal Area Precision Scheduling and Spacing System for near-term NAS application.* Proceedings from the Fourth International Conference on Applied Human Factors and Ergonomics, San Francisco, CA.

Walton, D., Quinn, C., & Atkins, S. (2002). *Human factors lessons learned from a Surface Management System Simulation.* Proceedings from the AIAA Aviation Technology Integration and Operations (ATIO) Conference. DOI: 10.2514/6.2002-5810

Witzberger, K. E., Martin, L. H., Sharma, S., & Robinson, J. (2015). Air traffic management - 1 (ATD-1): Operational Integration Assessment (OIA) final report.

Acronyms

ANOVA	Analysis of Variance
ATC	Air traffic control
ATCS	Air Traffic Control Specialist
ATM	Air traffic management
ATPA	Automated Terminal Proximity Alert
CPC	Certified Professional Controller
E/L	Early/late
EDA	En Route Descent Advisor
ERAM	En Route Automation Modernization
ETA	Estimated Time of Arrival
FAST	Final Approach Spacing Tool
HITL	Human-in-the-loop
ICS	Informed Consent Statement
M	Mean
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NATCA	National Air Traffic Controllers Association
NextGen	Next Generation Air Transportation System
NM	Nautical miles
P-GUI	Planview graphical user interface
P-FAST	Passive FAST
PSQ	Post-Scenario Questionnaire
PHL	Philadelphia International Airport
RPI	Relative Position Indicator
SARDA	Spot and Runway Departure Advisor
SD	Standard deviation
SME	Subject matter experts
STA	Scheduled time of arrival
STARS	Standard Terminal Automation Replacement System
T-GUI	Timeline graphical user interface
TAMR	Terminal Automation Modernization Replacement
TBID	Time-based information displays

TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control
TSAS	Terminal Sequencing and Spacing

Appendix A: Informed Consent Statement

Informed Consent Statement

I, _______________________________, understand that this study, entitled "Display of Time-Based Information for TRACON Air Traffic Control Specialists" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Dr. Todd R. Truitt.

Nature and Purpose:
I have been recruited to volunteer as a participant in this project. The purpose of this study is to evaluate concepts for the display of time-based information at the Air Traffic Control Specialist (ATCS) radar position in a Terminal Radar Approach Control (TRACON). The FAA will use the results of this study to provide human factors guidance on standard practices for the display of time-based information.

Experimental Procedures:
Each participant will possess skills at a Terminal Radar Approach Control (TRACON) facility rated as Level 10, 11, or 12. The participants will receive a briefing packet in the mail including this informed consent statement, instructions for participating in the study, and a set of questionnaires. Prior to the study, the researchers may provide additional instructions to the participants via email.

The researchers will conduct this study during a single WebEx meeting. Participants must have access to a FAA computer with an internet connection, FAA email, and a telephone. Once the participants log in to the WebEx site at the scheduled time, the researchers will provide an introductory briefing. The participants will complete the Informed Consent Statement and a background questionnaire. The researchers will then use a structured method to show the participants a prototype display and air traffic scenario and gather their feedback. The participants will observe the display, provide verbal feedback, and complete questionnaires as instructed. The researchers will also provide an open forum for the participants to discuss the prototype display and the time-based information concepts. The researchers and a Subject Matter Expert will take notes. The study will last for approximately 3 hours (1:00 PM – 4:00 PM Eastern Standard Time). The participants will get a 15-minute break about halfway through the study.

Discomfort and Risks:
As a participant in this study, I understand that I will not be exposed to any intrusive measurement techniques. I understand that I will not be exposed to any foreseeable risks beyond what I usually experience in my every day job.

Anonymity and Confidentiality:
My participation in this study is strictly confidential. All information that I provide will be anonymous to the experimenters. I understand that a participant code will be attached to my data for research purposes. My name and identity will not be released in any reports. All data collected in the study will be used for scientific purposes only and must be kept confidential by law. Laboratory personnel will not disclose or release any Personally Identifiable Information (PII) to any FAA personnel or elsewhere, or publish it in any report, except as may be required by statute. I understand that situations when PII may be disclosed are discussed in detail in FAA Order 1280.18 "Protecting Personally Identifiable Information (PII)".

Benefits:
I understand that I will be able to provide the researchers with valuable feedback and insight into the display of time-based information for TRACON ATCS. My data will help the FAA to establish the feasibility of new concepts. I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight regarding the display of time-based information. My data will help the FAA to develop human factors guidance on standard practices for the display of time-based information.

Participant Responsibilities:
Participants must have access to a FAA computer with an Internet connection, FAA email, and a telephone. I am aware that to participate in this study I must be a supervisory ATCS in the Terminal specialty. I will participate in the WebEx meeting, observe the prototype display and air traffic scenario, and answer any questions asked during the study to the best of my ability. I will not discuss the content of the study with other potential participants until the study is completed.

Participant Assurances:
I understand that my participation in this study is completely voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe it is in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

Dr. Truitt or a member of the research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Dr. Truitt or another member of the research team will be available to answer any questions concerning procedures throughout this study. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Dr. Truitt at (609) 485-4351.

Compensation and Injury:
I agree to immediately report any injury or suspected adverse effect to Dr. Truitt. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

Signature Lines:
I have read this informed consent statement. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:____Date:__________

Investigator:____Date:__________

Witness:____Date:__________

Appendix B: Background Questionnaire

Background Questionnaire

Instructions:
This questionnaire is designed to obtain information about your background and experience as an Air Traffic Control Specialist. Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

1. What is your **gender**?	○ Male		○ Female

2. What is your **age**?	_____ years

3. How long have you worked as an **ATCS (include FAA developmental, CPC, and military experience)**?	_____ years _____ months

4. How long have you worked as a **CPC for the FAA** (include Oceanic, En Route, TRACON, Tower)?	_____ years _____ months

5. How long have you **actively controlled traffic** in a TRACON facility?	_____ years _____ months

6. How many of the **past 12 months** have you actively controlled traffic in a TRACON facility?	_____ months

7. How long have you controlled traffic **using STARS**?	_____ years _____ months

8. Rate your current **skill as a CPC**.	Not Skilled	①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled

9. Rate your current **level of stress**.	Not Stressed	①②③④⑤⑥⑦⑧⑨⑩	Extremely Stressed

10. Rate your **level of motivation** to participate in this study.	Not Motivated	①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

Appendix C: Post-Scenario Questionnaire

Participant # ___________ **Date** ___________

Post-Scenario Questionnaire

Please answer the following questions based upon your experience in the user evaluation you just completed.

1. Rate the level of effort needed to determine if aircraft are on schedule.	Very Low	①②③④⑤⑥⑦⑧⑨⑩	Very High

Comments:

___

___

___

2. Rate the effort needed to identify which aircraft required intervention first.	Very Low	①②③④⑤⑥⑦⑧⑨⑩	Very High

Comments:

___

___

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Participant # ___________ **Date** ___________

The following questions relate to the presentation of time in the datablock. Please use your experience in the user evaluation to provide your answers.

3. Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to identify which aircraft required intervention first.	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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4. Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to notice when the difference between the ETA and STA was changing.	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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5. How did the use of fractions of minutes (e.g., 1.2, -0.5) impact your ability to determine which aircraft were on schedule?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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Participant # ___________ **Date** ___________

6. Rate the effort needed to interpret fractions of minutes (e.g., 1.2, -0.5) in the datablock.	Very Low	①②③④⑤⑥⑦⑧⑨⑩	Very High

Comments:

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7. Rate the effort needed to interpret the “E” and “L” indicators in the datablock.	Very Low	①②③④⑤⑥⑦⑧⑨⑩	Very High

Comments:

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8. Would you prefer the ability to toggle the time information (e.g., E0.5) on and off? Yes No (circle one)

Comments:

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Participant # ___________ **Date** ___________

The following questions relate to the presentation of color in the display. Please use your experience from the user evaluation to provide your answers.

9. Rate the effect that color coding had on your ability to identify which aircraft required intervention first.	Negative Effect	①②③④⑤⑥⑦⑧⑨ None	Positive Effect

Comments:

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10. Rate the effect that color coding had on your ability to notice when the difference between the ETA and STA was changing.	Negative Effect	①②③④⑤⑥⑦⑧⑨ None	Positive Effect

Comments:

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11. How does the use of color coding impact your ability to determine which aircraft were on schedule?	Negative Effect	①②③④⑤⑥⑦⑧⑨ None	Positive Effect

Comments:

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Participant # ___________ **Date** ___________

12. Rate the effort needed to interpret color coding in the datablock.	Very Low	①②③④⑤⑥⑦⑧⑨⑩	Very High

Comments:

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13. Would you prefer the ability to toggle the color coding on and off? Yes No (circle one)

Comments:

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Participant # ___________ **Date** ___________

The following questions relate to the presentation of the slot marker in the display. Please use your experience from the user evaluation to provide your answers.

14. Rate the effect that the location of the slot marker had on your ability to identify which aircraft required intervention first.	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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15. Rate the effect that the location of the slot marker had on your ability to notice when the difference between the ETA and STA was changing.	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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16. How does the location of the slot marker impact your ability to determine which aircraft were on schedule?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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17. Rate the effort needed to interpret the location of the slot marker in the datablock.	Very Low	①②③④⑤⑥⑦⑧⑨⑩	Very High

Comments:

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18. During the evaluation, did you ever associate a slot marker with the wrong aircraft? Yes No (circle one)

Comments:

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19. Would you prefer the ability to toggle the slot markers on and off? Yes No (circle one)

Comments:

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Participant # ___________ **Date** ___________

The following questions relate to the presentation of the general display concepts. Please use your experience from the user evaluation to provide your answers.

20. If the display concepts you saw today were in use at your facility, what effect do you think they would have on **air traffic safety**?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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21. If the display concepts you saw today were in use at your facility, what effect do you think they would have on **air traffic efficiency**?	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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22. If the display concepts you saw today were in use at your facility, what effect do you think they would have on **Air Traffic Control Specialist workload?**	Negative Effect	①②③④⑤⑥⑦⑧⑨ | None	Positive Effect

Comments:

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Participant # ___________ **Date** ___________

23. In your opinion, what time-based information should be added to the TRACON ATCS radar display?

Comments:

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24. Do you have any additional comments?

Comments:

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Appendix D: Post-Scenario Questionnaire Responses

Table D1. Descriptive statistics for the Post-Scenario Questionnaire

Item	*M*	*SD*
Q1 - Rate the level of effort needed to determine if aircraft are on schedule	2.50	0.58
Q2 - Rate the effort needed to identify which aircraft required intervention first.	4.75	1.71
Q3 - Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to identify which aircraft required intervention first.	4.00	2.58
Q4 - Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to notice when the difference between the ETA and STA was changing.	4.25	0.96
Q5 - How did the use of fractions of minutes (e.g., 1.2, -0.5) impact your ability to determine which aircraft were on schedule?	6.00	1.41
Q6 - Rate the effort needed to interpret fractions of minutes (e.g., 1.2, -0.5) in the datablock.	8.50	1.00
Q7 - Rate the effort needed to interpret the "E" and "L" indicators in the datablock.	2.50	1.91
Q8 - Would you prefer the ability to toggle the time information (e.g., E0.5) on and off?	1.00	0.00
Q9 - Rate the effect that color coding had on your ability to identify which aircraft required intervention first.	7.50	1.29
Q10 - Rate the effect that color coding had on your ability to notice when the difference between the ETA and STA was changing.	7.00	1.63
Q11 - How does the use of color coding impact your ability to determine which aircraft were on schedule?	7.50	1.00
Q12 - Rate the effort needed to interpret color coding in the datablock.	1.50	0.58
Q13 - Would you prefer the ability to toggle the color coding on and off?	0.75	0.50
Q14 - Rate the effect that the location of the slot marker had on your ability to identify which aircraft required intervention first.	6.25	0.96
Q15 - Rate the effect that the location of the slot marker had on your ability to notice when the difference between the ETA and STA was changing.	7.00	0.82
Q16 - How does the location of the slot marker impact your ability to determine which aircraft were on schedule?	7.25	0.96
Q17 - Rate the effort needed to interpret the location of the slot marker in the datablock.	3.25	3.20
Q18 - During the evaluation, did you ever associate a slot marker with the wrong aircraft?	0.00	0.00
Q19 - Would you prefer the ability to toggle the slot markers on and off?	1.00	0.00
Q20 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on air traffic safety?	5.00	0.00
Q21 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on air traffic efficiency?	6.25	1.50

Q22 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on Air Traffic Control Specialist workload?	3.25	1.50
Q23 - In your opinion, what time-based information should be added to the TRACON ATCS radar display?	1.00	0.00
Q24 - Do you have any additional comments?	1.00	0.00

Q1 - Rate the level of effort needed to determine if aircraft are on schedule.

- This seemed clear. I like the color system. Maybe red for late, yellow for early so that we can train the eye to react while processing at the same time.
- The effort is not much, but if the seconds are on there, it should be in exact seconds not fraction of seconds.

Q2 - Rate the effort needed to identify which aircraft required intervention first.

- I was not crazy about the fraction of time conversion. Add speed suggestions instead.
- Does ensuring aircraft are within the slot marker guarantee standard separation?
- Same answer as above. The fractions should be replaced with exact seconds. But that info is less important than an estimated speed to meet the time.

Q3 - Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to identify which aircraft required intervention first.

- I didn't like it. If I am working 10+ airplanes, I do not want to convert this then decipher what to do with each aircraft.
- It should be exact seconds not fractions. The fraction requires unnecessary thinking.

Q4 – Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to notice when the difference between the ETA and STA was changing.

- I could tell, but I was not a fan of this. I'd rather just be told (suggested) what to do. If this is a tool, then I'd rather it make things easier for me.
- Faster if shown in seconds.
- The colors of the bubbles were all that was needed.

Q5 – How did the use of fractions of minutes (e.g., 1.2, -0.5) impact your ability to determine which aircraft were on schedule?

- This was clear.

- The actual schedule is not as important as making sure the aircraft fits within the sequence. Hopefully the schedule ensures that they fit.
- Again, it should be in exact seconds.

Q6 – Rate the effort needed to interpret fractions of minutes (e.g., 1.2, -0.5) in the datablock.

- It wasn't hard, but I couldn't help but to think of how cumbersome it would be to try doing this for multiple aircraft when I am busy.
- The fractions of minutes could cause complexity during busy sessions. Either seconds or speed would be easier.
- Controllers not used to this unit of measure.
- They should be displayed in exact seconds.

Q7 – Rat the effort needed to interpret the "E" and "L" indicators in the datablock.

- This was clear. I would have liked to see E be one color and L be a different color rather than the color be determined by the fraction of minute to eliminate potential for errors.
- This too was unnecessary because the color of the bubble and location preference the bubble gave the necessary info. Everything else was clutter.

Q8 – Would you prefer the ability to toggle the time information (e.g., E0.5) on and off?

- I wouldn't use this on final, but I would try it on feeder.
- Option to accommodate personal preference always a bonus.
- Absolutely!

Q9 – Rate the effect that color coding had on your ability to identify which aircraft required intervention first.

- It brought my attention to the data tag, but I think Late should always be one color and Early should always be a different color.
- My opinion is the color is all that is needed. I would prefer a recommended speed in order to meet the time rather than the seconds.

Q10 – Rate the effect that color coding had on your ability to notice when the difference between the ETA and STA was changing.

- This was clear.
- Color is great!

Q11 – How does the use of color coding impact your ability to determine which aircraft were on schedule?

- It brought my attention to the datablock.
- Quicker to process.
- Excellent concept.

Q12 – Rate the effort needed to interpret color coding in the datablock.

- This was clear.
- Again, I like the color decoding.

Q13 – Would you prefer the ability to toggle the color coding on and off?

- No – I like the fact that the color gets my attention. Taking it off may allow me to overlook the details.
- Yes - Options always better.
- Yes – I like the color, but that doesn't mean everyone will.

Q14 – Rate the effect that the location of the slot marker had on your ability to identify which aircraft required intervention first.

- This was clear.
- The color was more important.

Q15 - Rate the effect that the location of the slot marker had on your ability to notice when the difference between the ETA and STA was changing.

- This was clearly understood.
- The location and colors are excellent.

Q16 – How does the location of the slot marker impact your ability to determine which aircraft were on schedule?

- This was easy to understand.
- It is important to ensure that the schedule ensures aircraft will fit within the sequence.
- The location is nice but the color has more value.

Q17 – Rate the effort needed to interpret the location of the slot marker in the datablock.

- This was clearly seen.
- Easy to understand.

Q18 – During the evaluation, did you ever associate a slot marker with the wrong aircraft?

- No.
- No. There is potential for this to happen. If the lead aircraft is early and the trailing aircraft is late, the two slot markers could be close.
- No. Possible issue with high volume.
- No.

Q19 – Would you prefer the ability to toggle the slot markers on and off?

- Yes. I will not want to see this while working final approach.
- Options.
- Yes. We should offer option to everyone's preference.

Q20 – If the display concepts you saw today were in use at your facility, what effect do you think they would have on air traffic safety?

- I think that controllers would still rely on distance based methods, especially within 20 miles of the airport.
- If controllers rely on slot markers to separate aircraft, then there can be a potential hazard.
- It would be a change of culture to focus on time and on time. Would increasing speeds to get more on time effect safety? I believe it could.

Q21 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on air traffic efficiency?

- I think this could be a positive thing. We could utilize this tool to help us when aircraft first check into our airspace.
- If there was not competing traffic, then slowing aircraft down to the slot marker would decrease efficiency.
- Too basic to impact efficiency.
- It would just change the focus from efficiency to who is on time.

Q22 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on Air Traffic Control Specialist workload?

- I think they would have too much to look at and too much to think about.
- Controllers could potentially assign control instructions to match the slot marker when nothing was needed prior. The next controller could see benefit though as long as the slot markers ensured separation.

- As long as it is optional.
- People would focus on time slots and not efficiency.

Q23 – In your opinion, what time-based information should be added to the TRACON ATCS radar display?

- Suggestions for speeds to accomplish the goal.
- During moderate to heavy volume times, the time-based information can increase efficiency to the airport. The slot marker and seconds has value to notify the controller if the aircraft needs to be "tweaked".
- Time to fix. Assistance resolving conflict points.
- The color coding is nice.

Q24 – Do you have any additional comments?

- Doe this model account for compression? When extra space is needed on final, the whole time concept goes out the window.
- The concept has potential to be very useful to the NAS.
- Not one size fits all. Could be beneficial to some operations/configurations but not all.
- Overall I believe it is a drastic change from solely efficiency to airlines being on time. As for the system, I like the color coding but I think a recommended speed to achieve that on time point would an improvement.

Appendix E: Summary Tables of Statistical Analyses

Table E1. Summary Table of T-Test Statistics

Item	*M*	*SD*	*t*-value	*p*-value	*d*
Q1 - Rate the level of effort needed to determine if aircraft are on schedule	2.50	0.58	10.392	0.002	5.196
Q2 - Rate the effort needed to identify which aircraft required intervention first.	4.75	1.71	0.878	0.444	0.394
Q3 - Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to identify which aircraft required intervention first.	4.00	2.58	0.775	0.495	0.387
Q4 - Rate the effect that using fractions of minutes (e.g., 1.2, -0.5) had on your ability to notice when the difference between the ETA and STA was changing.	4.25	0.96	1.567	0.215	0.783
Q5 - How did the use of fractions of minutes (e.g., 1.2, -0.5) impact your ability to determine which aircraft were on schedule?	6.00	1.41	1.414	0.252	0.707
Q6 - Rate the effort needed to interpret fractions of minutes (e.g., 1.2, -0.5) in the datablock.	8.50	1.00	6.000	0.009	3.000
Q7 - Rate the effort needed to interpret the "E" and "L" indicators in the datablock.	2.50	1.91	3.133	0.052	1.567
Q9 - Rate the effect that color coding had on your ability to identify which aircraft required intervention first.	7.50	1.29	3.873	0.030	1.936
Q10 - Rate the effect that color coding had on your ability to notice when the difference between the ETA and STA was changing.	7.00	1.63	2.449	0.092	1.225
Q11 - How does the use of color coding impact your ability to determine which aircraft were on schedule?	7.50	1.00	5.000	0.015	2.500
Q12 - Rate the effort needed to interpret color coding in the datablock.	1.50	0.58	13.856	0.001	6.928
Q14 - Rate the effect that the location of the slot marker had on your ability to identify which aircraft required intervention first.	6.25	0.96	2.611	0.080	1.306
Q15 - Rate the effect that the location of the slot marker had on your ability to notice when the difference between the ETA and STA was changing.	7.00	0.82	4.899	0.016	2.449
Q16 - How does the location of the slot marker impact your ability to determine which aircraft were on schedule?	7.25	0.96	4.700	0.018	2.350
Q17 - Rate the effort needed to interpret the location of the slot marker in the datablock.	3.25	3.20	1.406	0.255	0.703
Q20 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on air traffic safety?	5.00	0.00	0.000	1.000	0.000
Q21 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on air traffic efficiency?	6.25	1.50	1.667	0.194	0.833
Q22 - If the display concepts you saw today were in use at your facility, what effect do you think they would have on Air Traffic Control Specialist workload?	3.25	1.50	2.333	0.102	1.167

Table E2. Summary Table of ANOVA Statistics

Post Scenario Questionnaire Groupings	Conditions *M*(*SD*) Fractions of Minutes	Color Coding	Slot Markers	*F*-value	*p*-value	ηp^2
Rating of ability to identify which aircraft required intervention first (PSQ Items 3, 9, & 14)	4.00 (2.58)	7.50 (1.29)	6.25 (0.96)	3.744	0.088	0.555
Rating of ability to notice when the difference between the ETA and STA was changing (PSQ Items 4, 10, & 15)	4.25 (0.96)	7.00 (1.63)	7.00 (0.82)	15.783	0.004	0.840
Rating of ability to determine which aircraft were on schedule (PSQ Items 5, 11, & 16)	6.00 (1.41)	7.50 (1.00)	7.25 (0.96)	1.755	0.251	0.369
Rating of effort to interpret each element in the datablock (PSQ Items 6, 12, & 17)	8.50 (1.00)	1.50 (0.58)	3.25 (3.20)	11.443	0.009	0.792